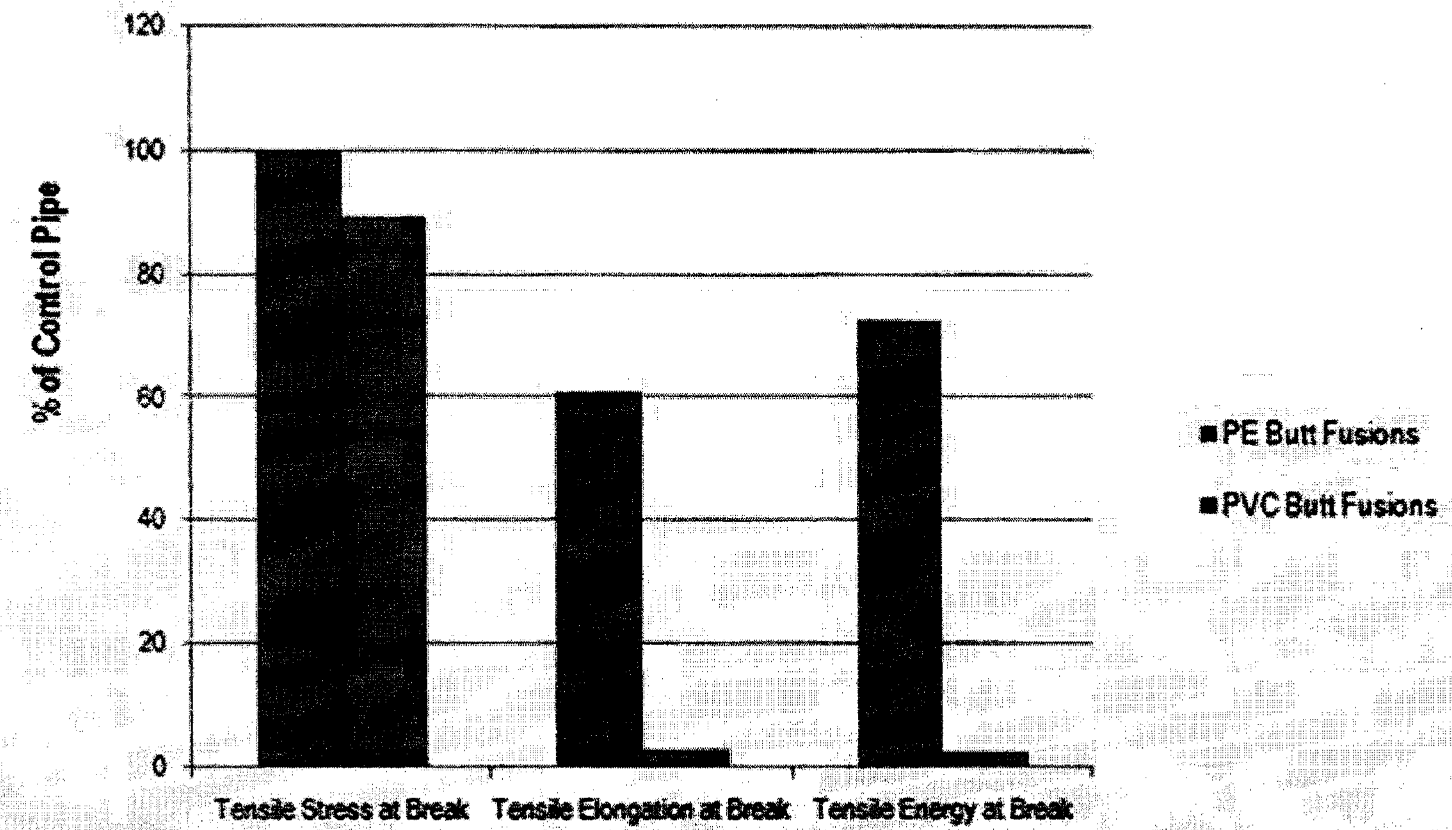
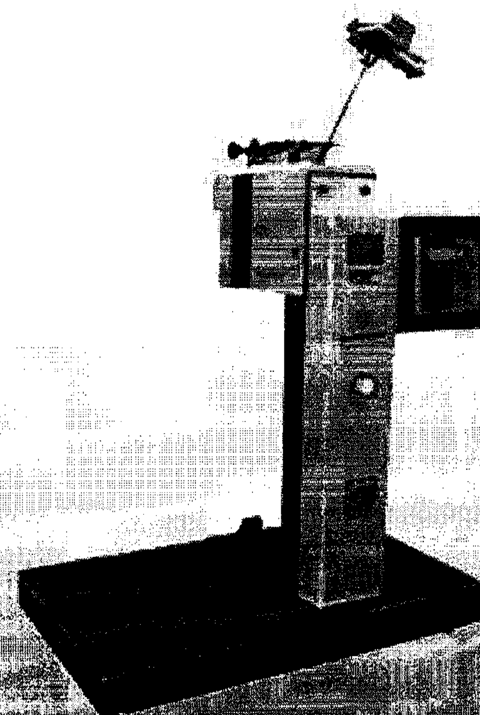
# ASTM D638 Tensile Results



# ASTM D1822 Tensile Impact Test

*"Standard Test Method for Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials"*

- Produces tensile impact load via pendulum swing
- ASTM D1822 method allows direct testing at joint interface
- Measures energy to break
- Energy to break is a key indicator of fusion joint quality



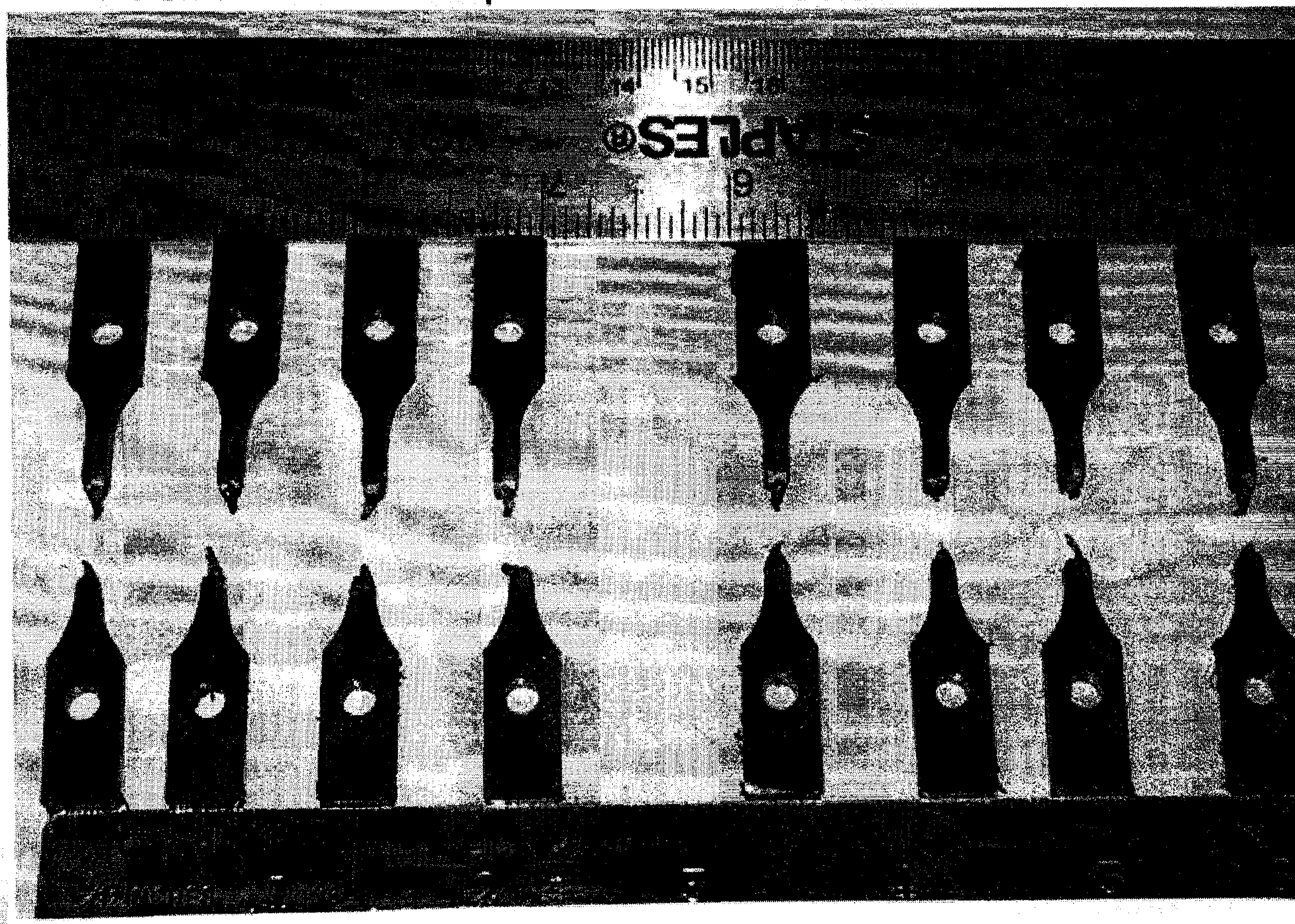
UGSI 00727

# PE Tensile Impact Results – ASTM D1822

| Test Property | Average Result |
|---|---|
| Corrected Impact Energy, Joint | 138.8 $kJ/m^2$ |
| Corrected Impact Energy, Control Pipe | 198.1 $kJ/m^2$ |
| % of Control | 70% |

LEFT SIDE – PE Control Pipe

RIGHT SIDE – PE Butt Fusion

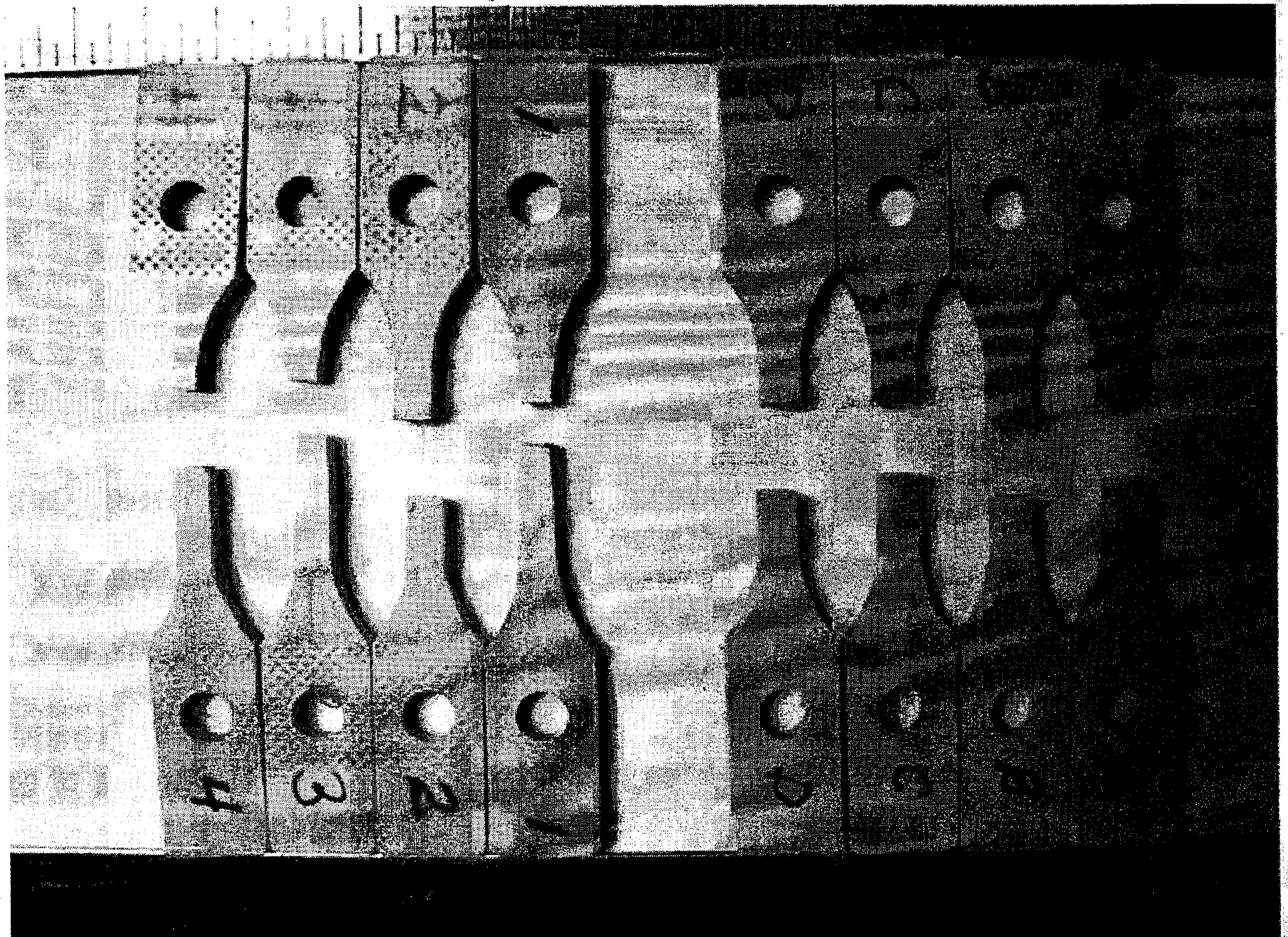


# PVC Tensile Impact Results – ASTM D1822

| Test Property | Average Result |
|---|---|
| Corrected Impact Energy, Joint | 26.6 $kJ/m^2$ |
| Corrected Impact Energy, Control Pipe | 590.1 $kJ/m^2$ |
| % of Control | 5% |

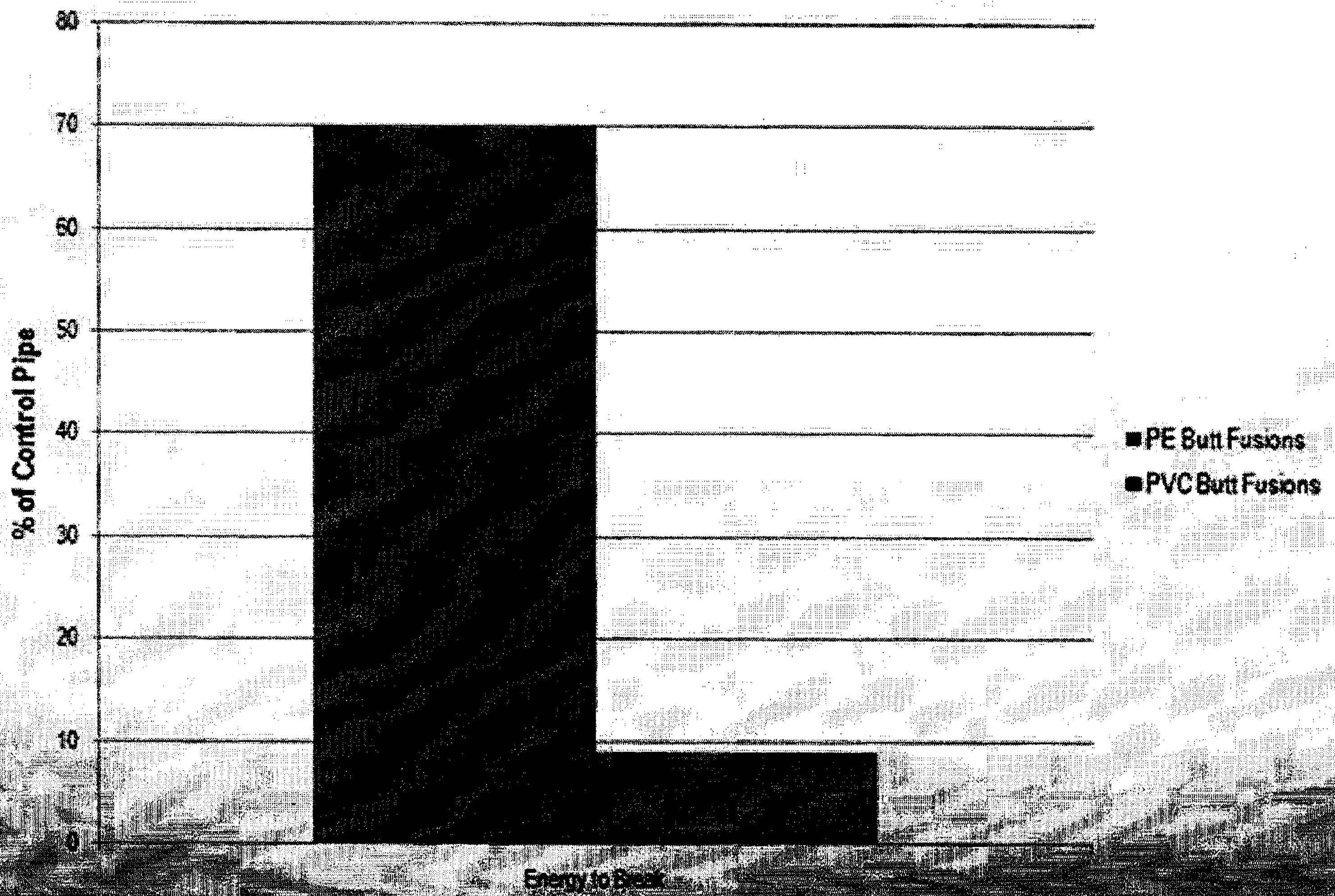
LEFT SIDE – PVC Control Pipe

RIGHT SIDE – PVC Butt Fusion



UGSI 00731

# ASTM D1822
# Tensile Impact Energy to Break

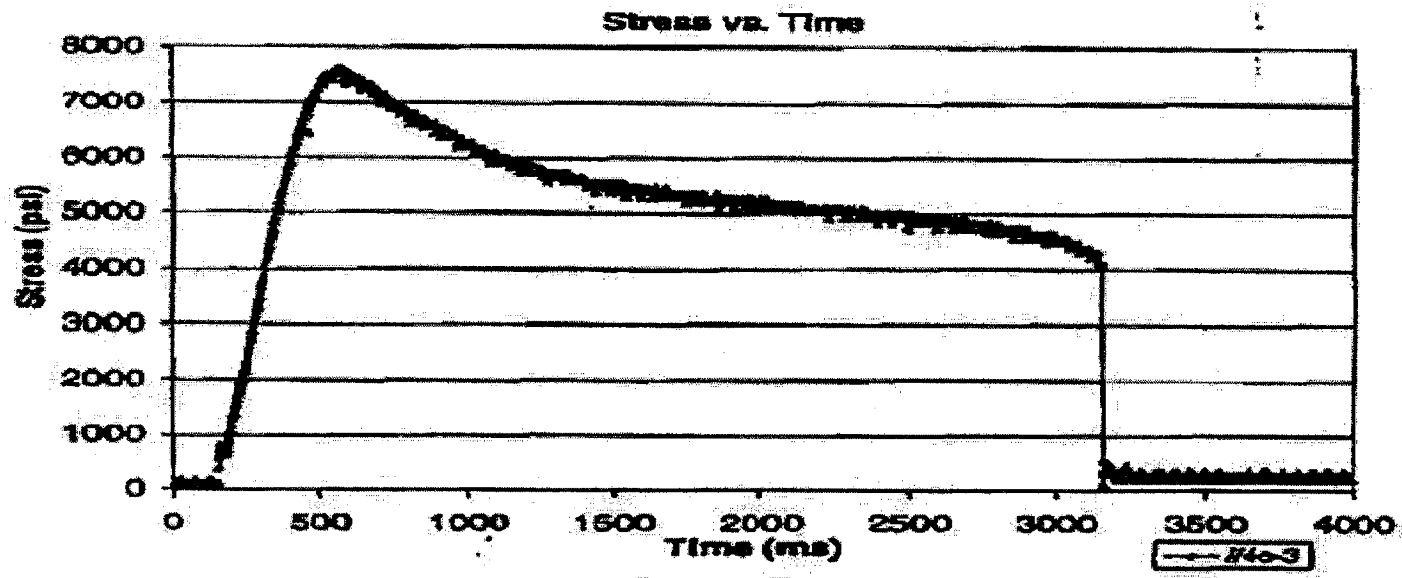


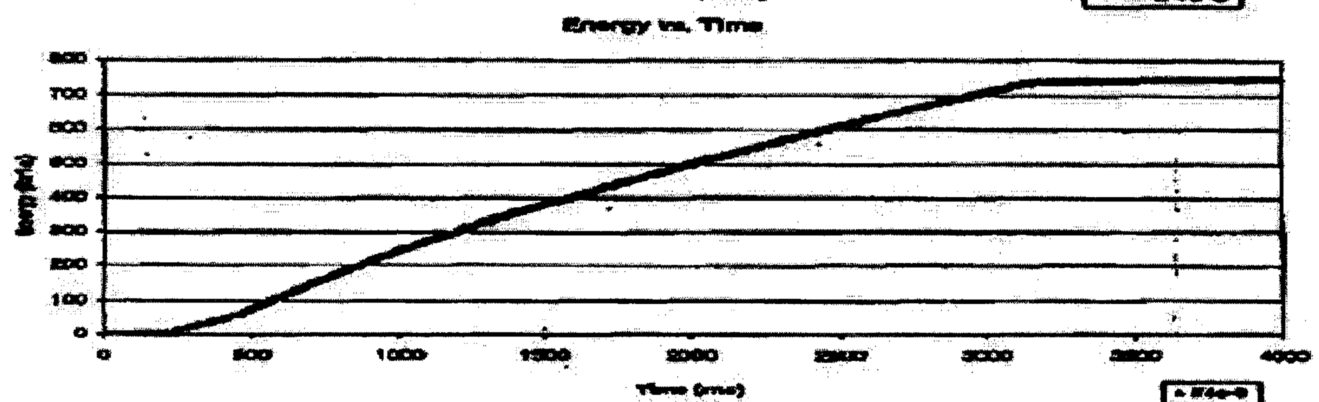
# ASTM F2634 Standard

*4. Significance and Use*

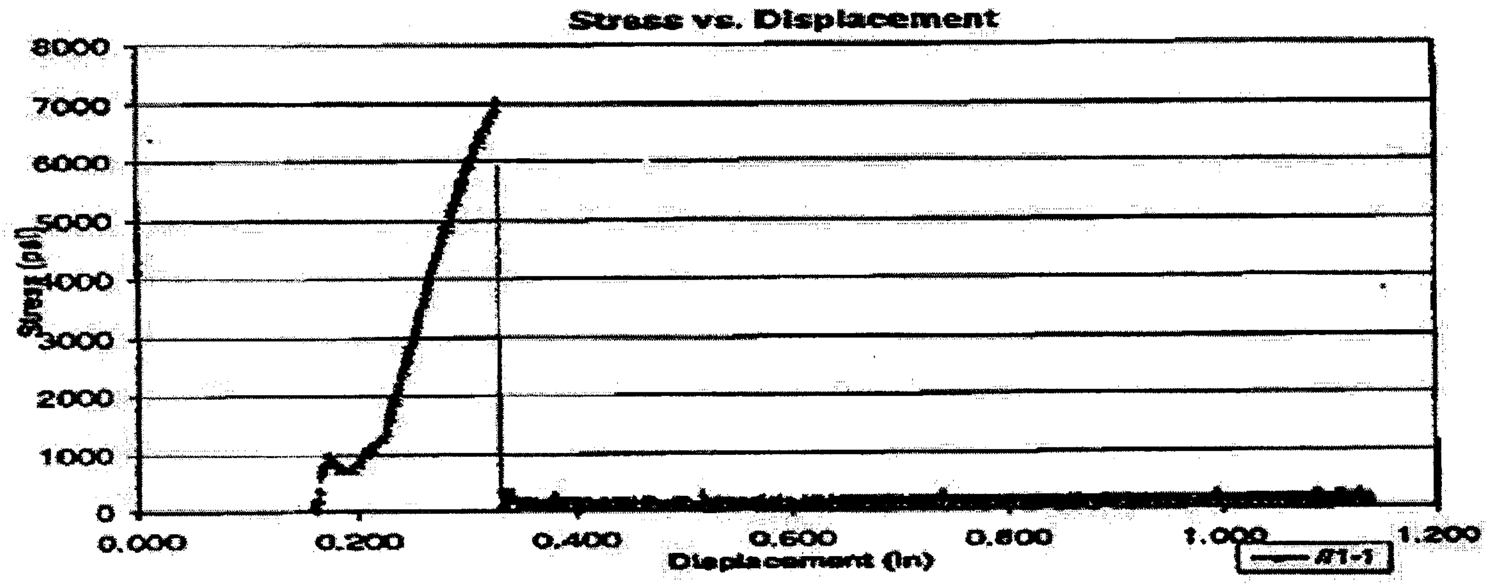
*4.1 This test method is designed to impart tensile impact energy to a butt fused plastic pipe specimen, record the energy to fail the specimen and plot the load over time curve of the tensile test. Energy recorded at yield and rupture and the rupture mode (brittle or ductile) are used as criteria in the evaluation of the butt fusion joint. The evaluation of the force/time curve not only makes it possible to compare different butt fusion parameters but also to evaluate the rupture mode of the specimen to determine joint integrity. Each coupon's test results will usually be compared to test results for coupons machined from the base pipe material, un-fused.*

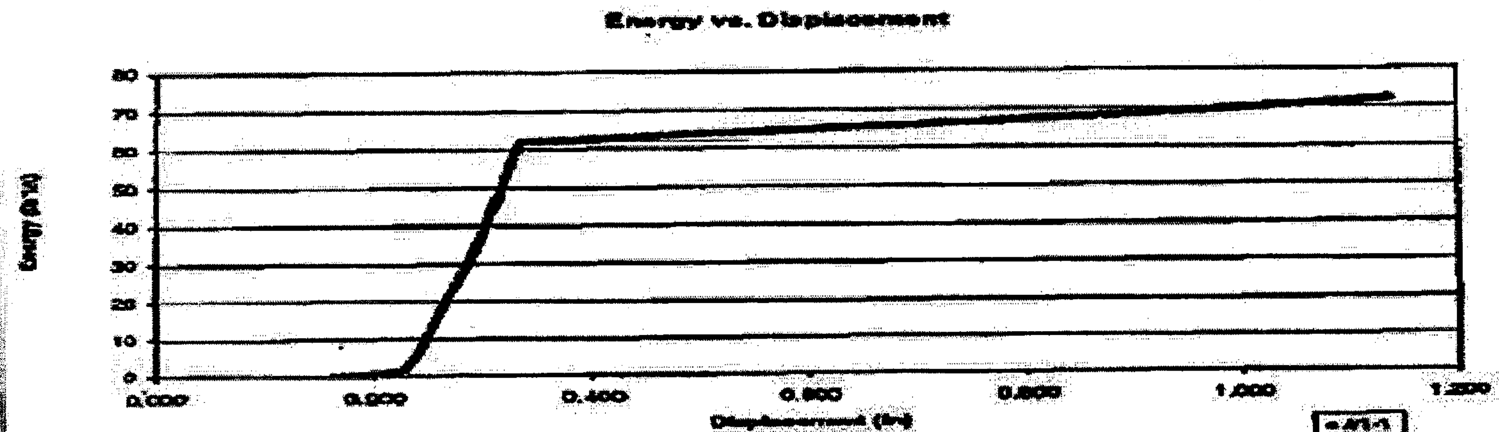
# F2634 - Control 8" PVC Pipe



# F2634 - Butt Fused 8" PVC Pipe



# High Speed Tensile Test Data

- High-speed tensile impact data using a modified version of ASTM F2634.
- The energy to break for this 8" PVC control pipe is about 750 ft-lbs/square inch; the energy to break for this 8" PVC butt fusion is about 70 ft-lbs/square inch, which is about 9% of the energy to break for the PVC control pipe.
- This value correlates well with the 9% energy to break of control pipe determined by ASTM D1822 tensile impact testing for PVC butt fusion joints.

*Underground Solutions, "Fusible C-900™/C-905™ PVC™ Test Data for Tensile and Pressure Properties of the Fusion Joint"

# OUTLINE

**RCP Failures in Butt Fused PVC Pipe**

- Known RCP Field Failures in Butt Fused PVC Pipe
- RCP Laboratory Data for PVC Pipe
- Proposals to Prevent RCP Failures in FPVC

**Butt Fusion Failures in PVC Pipe**

- Known Butt Fusion Field Failures in PVC Pipe
- Joint Integrity Laboratory Data for PVC Pipe
- Proposals to Prevent BF Failures in FPVC

# Recommendations

The following requirements should be added to industry standards for butt fused PVC pipe:

- The ASTM D638 tensile elongation for PVC butt fusion joints shall be at least 25% of the control pipe.
- The ASTM D1822 tensile impact or ASTM F2634 high-speed tensile impact energy-to-break shall be at least 25% of the control pipe.

# THANK YOU

## Prepared by

## Palermo Plastics

## Pipe ($P^3$) Consulting.

# Exhibit G

**IN THE UNITED STATES DISTRICT COURT**
**FOR THE NORTHERN DISTRICT OF ILLINOIS**

| | |
|---|---|
| UNDERGROUND SOLUTIONS, INC.,<br><br>Plaintiff,<br><br>v.<br><br>EUGENE PALERMO, a/k/a GENE PALERMO,<br><br>Defendant. | Case No.: 13-cv-08407<br><br>Assigned Judge: Matthew Kennelly<br><br>Magistrate Judge: Maria Valdez |

## UGSI'S SECOND SET OF REQUESTS FOR ADMISSION

Plaintiff, Underground Solutions, Inc., by its attorneys, Swanson, Martin & Bell, LLP, for its Second Set of Requests for Admission, states as follows:

**REQUEST NO. 1** Admit that the documents bates-labeled PAL #000333-000334 ($3,300.00), 000359-000360 ($1,575.00), 000375-000376 ($1,050.00), 000391-000392 ($525.00), 000407-000408 ($3,325.00), 000425-000426 ($5,301.04), 000442-000443 ($3,676.38), 000460-000461 ($540.00), 000476-000477 ($700.00), 000492-000493 ($675.00), 000509-000510 ($525.00), 000527-000528 ($4,268.39), 000545-000546 ($3,818.51), 001233-001234 ($700.00), 001246-001247 ($3,325.00), 001261-001262 ($3,109.30), 001276-001277 ($1,925.00), 001291-001292 ($2,100.00), 001306-001307 ($7,127.74), 001321-001322 ($700.00), 001336-001337 ($5,985.06), 001366-001367 ($1,575.00), 001381-001382 ($350.00), 001396-001397 ($4,940.38), 001411-001412 ($4,879.40), 001426-001427 ($1,100.00), 001441-001442 ($350.00), 001456-001457 ($875.00), are authentic copies of invoices submitted by you to Performance Pipe.

**REQUEST NO. 2** Admit that between 2010 and 2014, you were paid **no less than** $68,321.20 for services, including but not limited to making presentations, performed on behalf of

Performance Pipe.

**REQUEST NO. 3** Admit that the document bates-labeled **PAL #000782-000783** ($750.00), **000797-000798** ($5,289.76), **000857-000860** ($2,826.63), **000887-000888** ($4,200.00), **000902-000903** ($8,522.30), **002686-002689** (4,246.12), and **Alliance #000678-000679** ($150.00), **000697-000698** ($4,250.00) are authentic copies of invoices submitted by you to the Alliance for PE Pipe.

**REQUEST NO. 4** Admit that between 2013 and 2015, you were paid **no less than** $30,234.81 for services, including but not limited to making presentations, performed on behalf of the Alliance for PE Pipe.

**REQUEST NO. 5** Admit that the document bates-labeled **PAL #000826-000827** ($6,329.21), **000872-000873** ($8,133.12), **000917-000918** ($10,982.25), **001172-001173** ($6,621.30), **001187-001188** ($3,025.00), **001202-001203** ($2,200.00) are authentic copies of invoices submitted by you to P&F Distributors.

**REQUEST NO. 6** Admit that between 2012 and 2014, you were paid **no less than** $37,290.88 for services, including but not limited to making presentations, performed on behalf of the P&F Distributors.

**REQUEST NO. 7** Admit that the document bates-labeled **PPI #000187** ($1,493.16) is an authentic copy of an invoice submitted by you to the Plastics Pipe Institute (PPI).

**REQUEST NO. 8** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #000323.**

**REQUEST NO. 9** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #000327.**

**REQUEST NO. 10** Admit the authenticity of the e-mail reflected in the document bates-

labeled **PAL #000618.**

**<u>REQUEST NO. 11</u>** Admit the authenticity of the e-mails reflected in the documents bates-labeled **PAL #000170-000173.**

**<u>REQUEST NO. 12</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #000277.**

**<u>REQUEST NO. 13</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #000616.**

**<u>REQUEST NO. 14</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #002390.**

**<u>REQUEST NO. 15</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #002419.**

**<u>REQUEST NO. 16</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #002440.**

**<u>REQUEST NO. 17</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #002496.**

**<u>REQUEST NO. 18</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #002451.**

**<u>REQUEST NO. 19</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #002584.**

**<u>REQUEST NO. 20</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #002743.**

**<u>REQUEST NO. 21</u>** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #002857.**

**REQUEST NO. 22** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #002991.**

**REQUEST NO. 23** Admit the authenticity of the e-mail reflected in the document bates-labeled **PAL #003016.**

*Respectfully submitted,*

By::__/s/ Christopher T. Sheean________
One of the attorneys for Plaintiff Underground Solutions, Inc.

Christopher T. Sheean, ARDC #6210018
Swanson, Martin & Bell LLP
330 North Wabash Avenue, Suite 3300
Chicago, Illinois 60611
(312) 321-9100
csheean@smbtrials.com

## CERTIFICATE OF SERVICE

The undersigned herby certifies and declares under penalty of perjury, pursuant to 28 U.S.C. §1746 that the attached **UNDERGROUND SOLUTIONS, INC.'S SECOND SET OF REQUESTS FOR ADMISSION** was caused to be served by electronic mail on the 4th day of December, 2015 to the Palermo's counsel of record.

s/ Steven L. Vanderporten
Steven L. Vanderporten (ARDC # 6314184)
Swanson, Martin & Bell, LLP
330 N. Wabash Ave.
Suite 3300
Chicago, Illinois 60611
(312) 321-9100
svanderporten@smbtrials.com

# Exhibit H

IN THE UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION

UNDERGROUND SOLUTIONS, INC., Plaintiff,

vs. No. 13-cv-08407

EUGENE PALERMO, a/k/a GENE PALERMO, Defendant.

The video teleconferenced deposition of PATRICK LEEVERS, Ph.D., called for examination pursuant to the Rules of Civil Procedure for the United States District Courts pertaining to the taking of depositions, taken before BRENDA S. TANNEHILL, CSR, at 330 North Wabash Avenue, Chicago, Illinois, on March 14, 2016 at the hour of 9:11 o'clock a.m.

REPORTED BY: Brenda S. Tannehill, CSR, RPR, CRR
LICENSE NO. 084-003336



APPEARANCES:

SWANSON, MARTIN & BELL
BY MR. CHRISTOPHER T. SHEEAN
330 North Wabash Avenue, Suite 3300
Chicago, Illinois 60611
(312) 321-9100
csheean@smbtrials.com
Representing the Plaintiff;

MANDELL MENKES, LLC
BY MR. JOHN D. FITZPATRICK
One North Franklin, Suite 3600
Chicago, Illinois 60606
(312) 251-1000
jfitzpatrick@mandellmenkes.com
Representing the Defendant.



I N D E X



E X H I B I T S





(Whereupon, Leevers Deposition Exhibit No. 1 was marked for identification.)

(Whereupon, the witness was duly sworn.)

MR. SHEEAN: Dr. Leevers, my name is Christopher Sheean, and I represent Underground Solutions, Incorporated in a lawsuit that's pending here in the Northern District of Illinois against Eugene Palermo.

I understand that you've been retained as an expert witness in this case.

THE WITNESS: That's correct.

MR. SHEEAN: I also understand that you've been deposed previously, but just to make sure that we're operating on the same wavelength, I'm going to go over sort of the ground rules so that we get a good transcript from our court reporter. Okay?

THE WITNESS: Okay.

MR. SHEEAN: Great.

I'm going to be asking you a series of questions. They're going to be out loud and verbal just as we're speaking now, and for each

understand the relationship between those two graphs.
The one which cannot be explained was the one previous graph which shows a, quote, 100 percent air test at 1.7 bars.
Q. Okay.
A. I exchanged e-mail with Dr. Choi, and I still don't understand either that particular point or the relationship between -- the exact relationship between points on the critical pressure-versus-air volume curve and the data points of the previous curve that gives crack length versus pressure.
(Whereupon, Leevers Deposition Exhibit No. 3 was marked for identification.)
BY MR. SHEEAN:
Q. One of the documents that you were sent which we're going to mark as Exhibit 3 right now was your paper with Chris Greenshields, "The Effects of Air Pockets on Rapid Crack Propagation in PVC and Polyethylene Water Pipe" from Plastics, Rubber and Composites Processing and Application from 1995.



You're familiar with that paper, right?
A. Yes. I have it in front of me.
Q. Great. I just have one question.
On Page 11 under the conclusions of that document, under the conclusions, you say in the second sentence, "Cracks were able to propagate in 125-millimeter-diameter S4 pipe test specimens at 2.3 bar with 10 percent air volume."
Do you see that?
A. Yeah. I think it's -- I'm not sure that it says 2.3 or 223. I think it's 2.3. That's 125 SDR.
Q. Okay. On Page 12 of your report, you state that you do not consider Dr. Palermo's application of the S4 test data to be misleading, correct?
A. Correct.
Q. Going back to Exhibit 2 which is the presentation to the MRWA dated 3/20/13, do you see that?
A. Yes, or I will in a second. Yes.
Q. Unfortunately, the slide show that I sent you is not page numbered so if you could



turn to about almost halfway through the presentation, there's a slide titled "Critical Pressure Versus Pressure Rating For PVC."
A. Rapid crack propagation critical pressure test methods to determine full-scale tests -- ISO 13477 -- correlation equation --
Q. That's it, that's it.
A. Okay. Yeah.
Q. All right. On that slide, do you see that there's a reference at the bottom, a star, to your study that we've just marked as Exhibit 3? Yes?
A. Yes.
Q. And then above that where the star is referenced, it says, "The critical pressure of the S4 test was 1.6 bar for DR19 PVC pipe with air equal to or greater than 10 percent air."
Do you see that?
A. Yes.
Q. Doesn't your study actually find that the critical pressure was 2.3 bar in the reference we just made?
A. I'm trying to find that paper now because I think that is correct. I think I've



got too much paper now. Yes.
Q. So, in fact, Doctor, --
A. Hold a second.
Q. Sorry.
A. Yeah, yes.
Q. So Dr. Palermo has miscited the critical pressure found in your study with 10 percent air, hasn't he?
A. I'm looking at Figure 3, "Variation of Critical Pressure With Air Volume." That gives a critical pressure of 2.3 at 10 percent.
Q. And Dr. Palermo has identified it as 1.6, hasn't he?
A. Yes. That's incorrect.
Q. Okay. Dr. Palermo is incorrect in his reference, correct?
A. Yes.
Q. So if he uses that number and then runs it through the correlation equation to come up with a critical pressure of 121 pounds per square inch, that ultimate result is still going to be incorrect because he started with the wrong critical pressure before the correlation factor, correct?

not expect it to be possible to produce a PVC with higher RCP resistance, something to that effect. Do you recall that testimony?

A. I would be surprised if it was possible to produce a PVC with much higher RCP resistance, yes.

Q. And why would you be surprised by that?

A. Because this is something I've done a certain amount of research on. In several of the papers, you'll see that we've used a model of what RCP -- how RCP works, what it is, to predict the RCP resistance of polymers and principles and properties, and what really matters is molecular weight. It's the thing that matters above all.

There's not a great deal you can do about increasing -- you can make PVC with higher molecular weight, and it will have higher RCP resistance. The problem is that it then becomes very difficult to extrude, in order to extrude it without overheating it if you overheat it without damaging the properties.

So in my opinion -- and I'm not a formal chemist, but I would be surprised if

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conventional PVC was -- it's possible to produce one easily which could be extruded and have that RCP resistance much above the first.

MR. FITZPATRICK: Nothing further.

MR. SHEEAN: No further questions.

Thank you for your time today, Doctor, and for bearing with us on the technology problems that we had.

Do you want to reserve signature?

MR. FITZPATRICK: Please. We'll reserve.

(Whereupon, the proceedings concluded at 11:25 a.m.)

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UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION

UNDERGROUND SOLUTIONS, INC., Plaintiff,
vs. No. 13-cv-08407
EUGENE PALERMO, a/k/a GENE PALERMO, Defendants.

This is to certify that I have read the transcript of my deposition taken in the above-entitled cause by BRENDA S. TANNEHILL, Certified Shorthand Reporter, on March 14, 2016, and that the foregoing transcript accurately states the questions asked and the answers given by me as they now appear.

______________________________
PATRICK LEEVERS, Ph.D.

SUBSCRIBED AND SWORN TO before me this ______, day of _ ______________ 2016.

______________________
Notary Public

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C E R T I F I C A T E

I, BRENDA S. TANNEHILL, do hereby certify that heretofore, to-wit, on March 14, 2016, personally appeared before me via video teleconference at 330 North Wabash Avenue, Chicago Illinois, PATRICK LEEVERS, Ph.D., in a cause now pending and undetermined in the United States District Court, Northern District of Illinois, wherein UNDERGROUND SOLUTIONS, INC. Is the Plaintiff, and EUGENE PALERMO, a/k/a GENE PALERMO is the Defendant.

I further certify that the said witness was first duly sworn to testify the truth, the whole truth and nothing but the truth in the cause aforesaid; that the testimony then given by said witness was reported stenographically by me in the presence of the said witness, and afterwards reduced to typewriting by Computer-Aided Transcription, and the foregoing is a true and correct transcript of the testimony so given by said witness as aforesaid.

I further certify that the signature to the foregoing deposition was not waived by

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# Exhibit I

# Expert Report

UGSI v. Eugene Palermo
ESI Project: 50642A

4215 Campus Drive
Aurora, IL 60504

# Expert Report

UGSI v. Eugene Palermo
ESI Project: 50642A

**Report Prepared for:**

Swanson, Martin & Bell, LLP
330 N. Wabash Ave., Suite 3300
Chicago, IL 60611

**Submitted by:**

Dale B. Edwards

Dale B. Edwards, P.E.
Senior Managing Consultant
IL P.E. | Expires: November 30, 2017

DALE B. EDWARDS
062-041364
LICENSED
PROFESSIONAL
ENGINEER
STATE OF ILLINOIS

December 17, 2015
Date

## Introduction

Dale B. Edwards, P.E., of Engineering Systems Inc. (ESI) was retained by Mr. Christopher T. Sheean of Swanson, Martin & Bell, LLP on behalf of Underground Solutions, Inc. (UGSI) to provide a critical review of presentations and publications by Eugene Palermo concerned with fusible PVC pipe and rapid crack propagation (RCP). Dr. Palermo's presentations and publications constitute an attack on the business of UGSI and contain many errors that were known to him and yet he continued to present them as fact.

This report is based upon a review of the presentations and publications that Dr. Palermo has made over several years on the subject of RCP and Fusible PVC pipe. This includes the author's review of this material, including a review of standards and literature related to the issues of this case, and the author's experience in plastic piping, including Fusible PVC and polyethylene pipe, plastics failure analysis and testing of plumbing products, and RCP S4 testing of pipe materials. ESI reserves the right to augment or revise the conclusions of this report if additional information becomes available that warrants it.

## Qualifications of Dale B. Edwards, P.E.

I am currently a Senior Managing Consultant at Engineering Systems Inc. (ESI), a materials and forensic engineering consulting firm with offices in 8 states. I have been involved in consulting, failure analysis, analytical testing, and mechanical testing of plastics since 1979. I have been extensively involved with plastic pipe and tubing issues in my career, having previously worked for Bodycote Polymer - Broutman Laboratory (BPBL – formerly known as L.J. Broutman & Associates) for over 24 years, where I participated in ASTM and Plastics Pipe Institute (PPI) activities. I have consulted with many gas, water and sewer utilities, as well as many major plastic resin manufacturers. I am a co-author of the book, **Fractography in Failure Analysis of Polymers**, which was published in May, 2015.

I have a degree in Chemical Engineering from The University of Illinois and have taken graduate materials courses at Illinois Institute of Technology. I am a registered professional engineer in the State of Illinois, license number 062-041364. I have been involved in testing and analyzing plastics, including all types of plastic pipe and tubing for over 30 years. In particular, I have been involved in hundreds of projects involving pipe, tubing and fittings used in gas distribution systems, hot and cold-water plumbing systems, water distribution systems, sewer systems and pipe carrying hydrocarbon-based fuels and oils. This includes extensive failure analysis work on plastic piping materials including fusible PVC pipe. My experience includes on-site inspection of hundreds of installations of pipe and plumbing materials and I have examined thousands of failed pipe and fitting samples. I was in charge of the pipe test laboratory at BPBL, conducting long-term and short-term tests on various types of plastic piping materials. My work experience also includes mechanical testing, analytical testing, consulting, failure analysis, laboratory management and legal consulting.

I have been a member of ASTM Committee F-17 on Plastic Piping Systems for approximately the last twenty-six years. I was formerly the Secretary of the Water Subcommittee (F17.61). I also have previously been active in the Plastics Pipe Institute (PPI) as the company representative for BPBL. My involvement in PPI and ASTM has included the development of a test method as part of the Alternate Methods Committee (PPI Hydrostatic Stress Board committee). This test method has been published as ASTM F 2018, “Standard Test Method for Time-to-

Failure of Plastics Using Plane Strain Tensile Specimens". This test method is an alternate method for determining the hydrostatic design basis (HDB) of plastic piping materials.

I am currently a Senior Member of The Society of Plastics Engineers (SPE), and have maintained membership in SPE since 1981. I am a former Chairman of the Failure Analysis and Prevention Special Interest Group (FAPSIG) of SPE and have been the Technical program Chair of FAPSIG and a past Board member of the Medical Plastics Division of SPE.

Many of my publications have involved plastic piping products and failure analyses, including studies for the National Transportation Safety Board (NTSB) and an aging study conducted on plastic gas pipe for the Gas Research Institute. I have taught seminars for many years including the Fracture Analysis Workshop, which was co-sponsored by The Society of Plastics Engineers (SPE) and I have taught similar courses on Failure Analysis and Testing of Plastics. I taught these seminars as part of Bodycote Polymer's Failure Analysis Series for 14 years (1995 – 2008). ESI has begun sponsoring these seminars on a yearly basis as well, starting in June, 2015. My curriculum vitae is attached as Appendix I, which further outlines my experience, as well as a history of deposition and trial testimony in Appendix II.

## Materials Reviewed

Many of the materials reviewed include those listed in the reference section at the end of this report. Other materials reviewed include the following:

1. Exhibits 1 through 9 to the deposition of Dr. Eugene Palermo that was taken in this case.
2. Presentation by Tom Marti, of UGSI, Setting the Record Straight – ISO S4 Testing of AWWA C900 Pipe, ASCE Pipelines Conference, 2015.
3. Analysis of 18-inch DR25 PVC Pipe from Chatham Water District, D.B. Edwards, ESI Project 24600A, May 5, 2011.
4. Analysis of 18-inch DR25 PVC Pipe from Chatham Water District – Addendum Report, D.B. Edwards, ESI Project 24600A, August 8, 2011.
5. Analysis of a 16-inch DR31 PVC Pipe from Salt Lake City, Utah, D.B. Edwards, ESI Project 24600A, June 6, 2012.
6. Failure Analysis of a 12" DR18 PVC Pipe from Solyndra, D.B. Edwards, ESI Project 24600A, October 10, 2010.
7. Inspection of a 20-inch DR21 PVC Pipe from Dorchester Road in Charleston, SC, D.B. Edwards, ESI Project 24600A, August 8, 2012.
8. Analysis of a 16-inch DR21 PVC Pipe from Watford City, ND, D.B. Edwards, ESI Project 24600A, April 4, 2013.
9. Failure Analysis of a 36" DR 32.5 PVC Pipe, D.B. Edwards, ESI Project 24600A, January 20, 2010.
10. Failure Analysis of a 24" DR 25 PVC Pipe Foster Rd., LA, D.B. Edwards, ESI Project 24600A, July 7, 2010.
11. Des Moines, IA Fracture Investigation, D.B. Edwards, ESI Project 24600A, September 9, 2008.

12. Underground Solutions Consulting (Greencastle), D.B. Edwards, ESI Project 24600A, September 9, 2007.
13. Underground Solutions Consulting, D.B. Edwards, ESI Project 24600A, September 9, 2007.
14. Duvall, D.E. and Edwards, D.B., *Failure Analysis of a Large Diameter Heat-Fusible PVC Pipe in a Horizontal Directional Drilling Installation*, Proceedings of the Society of Plastics Engineers Annual Technical Conference, Milwaukee, WI, May 4-7, 2008.
15. Edwards, D.B. and Jeka, T.J., *Failure Analysis of a 30-inch DR25 PVC Pipe*, Bodycote Polymer-Broutman Laboratory Report, Project 30003799, January 23, 2007.
16. Malcolm Pirnie, *South Reverse Osmosis Wellfield Transmission Main Failure Preliminary Report*, April 2010.
17. Greenshields, C.J., et al., *The Effect of Air Pockets on Rapid Crack Propagation in PVC and Polyethylene Water Pipes*, Plastics Rubber and Composites Processing Applications **24** (1), pp. 7-12, (1995).
18. ISO 13477, *Thermoplastics Pipes for the Conveyance of Fluids – Determination of Resistance to Rapid Crack Propagation (RCP) – Small-scale Steady-state Test (S4 Test)*, ISO, 2008.
19. British Standard Specification for Unplasticized Polyvinyl Chloride (PVC-U) Pressure Pipe for Cold Potable Water, BS 3505:1986.
20. Greenshields, C.J., et al., *Rapid Crack Propagation in Plastic Water Pipes: Measurement of Dynamic Fracture Resistance*, **International Journal of Fracture**, 79, 1996.
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25. Anon, ASTM E2332, Investigation and Analysis of Physical Component Failures, ASTM International, West Conshohocken, PA, 2010. 
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## Review of Gene Palermo's Presentation to the Michigan Rural Water Association (MRWA)

Dr. Eugene Palermo has written several papers and presentations that purport to address a "problem" with fusible PVC pipe, that problem being "susceptibility" to rapid crack propagation (RCP) failures. His presentations are misleading and contain several false statements and appear to be designed to promote HDPE pipe and to harm the business of UGSI. Dr. Palermo was paid to make these presentations on behalf of a polyethylene pipe producer and on behalf of the Plastics Pipe Institute, which is the primary trade organization for polyethylene pipe manufacturers. In most cases, Dr. Palermo did not disclose this fact to his audiences. Dr. Palermo's presentations

create the impression that fusible PVC pipe is an RCP failure waiting to happen, which is inaccurate. His presentations intentionally leave out important facts about the cause of the failures that he describes as "RCP field failures". His "design method" does not include the most important aspects of the situation, namely how RCP and other failures can be prevented.

One would expect an expert who is providing information regarding the failure of a piping system to provide some level of scientific analysis that involves inspection, testing, analysis of the subject pipe failures and a review of the scientific literature. In his deposition testimony, Dr. Palermo has admitted that he has not examined any of the pipe failures that he lists as RCP field Failures in his presentations. He also has not conducted any testing or performed any analysis on these pipe failures. Palermo does not mention the specific cause(s) of any of the failures, but only the mode of failure, i.e. that they resulted in long cracks in the pipe. Palermo does not even provide the source of most of the information that he uses in the presentations.

**Failure Analysis Methodology**

The object of a failure analysis is to determine the root cause of the failure - what happened and how and why it happened. This involves putting together information and examining the evidence so as to get as complete a picture of the incident as possible. Examination of field samples, which include the failed section, is of primary importance in determining the cause of failure. [5] If one is reasonably assured that the sample has not been altered from its in-service state, the cause of failure can often be determined. It is generally possible to determine whether the cause of failure is related to the material, processing, installation/handling, or the in-service environment. Visual and microscopic examinations of the samples are performed along with dimensional measurements, and, where possible or pertinent, mechanical testing and/or analytical testing are performed in order to aid in determining the cause of failure. The cause of failure is very different from the "failure mode" or "failure mechanism" and must not be confused. The distinction is important. *Mode* refers to the actual mechanisms or processes by which failure occurs and how those mechanisms are manifested physically, whereas *cause* refers to the various factors that initiate and drive the processes. [5]

In the case of failures of plastic piping, it can be very helpful to visit the actual site of the incident in order to see the nature of the failure, the configuration of the site and obtain information from those who were present. Failures in plastic pipes occur due to a variety of causes:

**Material**: poor long-term strength, ineffective anti-oxidant, degradation

**Manufacturing (extrusion)**: improper measurements, voids in wall, contaminants in wall, weak weld lines (spider lines), degradation due to overheating/shearing

**Installation**: excessive bending, installation damage, improper fitting assembly, improper support/backfill, improper use of other materials, impact damage, overstressing, bad fusion of joints

**System Operation**: over pressurization, excessive stress-bending/flattening, large pressure surges, entrapped air, excessive temperature, chemical exposure, UV exposure

The failure analysis process usually involves collection and examination of the evidence on site and later in the laboratory, along with information obtained from people involved with the incident. Dr. Palermo has not performed any of these steps according to his own deposition testimony and has not conducted an investigation that adheres to the scientific method.

**MRWA Presentation**

Dr. Palermo's presentations are all similar in nature and are typified by the presentation, *Plastic Pipe for Water Distribution – What You Need to Know about RCP and Butt Fusion Integrity*, which was presented at the Michigan Rural Water Association (MRWA) meeting held on March 20, 2013. The following will address the false and misleading statements that were made in this presentation regarding RCP of fusible PVC and HDPE pipes that occur in the first 34 slides of the presentation.

First of all, the title purports to convey "what you need to know" to the water industry personnel in attendance. It is presented as fact, even though many facts are left out and includes many false and/or misleading statements. Palermo starts out with a list of twenty "Known RCP Field Failures in Butt-Fused PVC Pipe" (slide 3). This list is not a list of in-service failures of the pipe, as the vast majority of them are related to installation and pressure testing prior to being put into service. There are several false statements in the table where Dr. Palermo states a length of crack, which in some cases is completely wrong and in others is unknown.

It is not surprising that Dr. Palermo's analysis contains many errors since he did not investigate any of them. It is extremely important that an investigator conduct a proper scientific analysis in order to determine the root cause of the failures. This involves more than gathering information from nameless people, but must involve actual examination of the evidence and testing of the materials involved. The basic components of a failure investigation should be followed [5,6] including:

- Collection of Evidence and Background Data
- Testing and Analysis of Failed Components
- Analysis of Test Data
- Assessment of Failure Mechanism(s) and Causes

These are very general categories, but include site inspections, examination of the physical evidence and appropriate testing. As stated above, Dr. Palermo has done none of these things for any of the failure cases he cites in the table. In contrast to this, the author has investigated 70 percent of the incidents (14/20) on the list, participating in site inspections, examinations of the failed pipes and in some cases laboratory testing on the pipe samples. The following table transcribes the information in Palermo's slide #3 and adds to it a column indicating whether an analysis was performed by ESI.

| No. | RCP Failure Location | Date of RCP Failure | Pipe Size and DR | Length of RCP Crack | Joined by Butt Fusion | Analysis by ESI? |
|---|---|---|---|---|---|---|
| 1 | Winter Park, FL | 2004 | 8" DR18 | 200 ft | Y | N |
| 2 | Danville, CA | 2006 | 20" DR 18 | 400 ft | Y | N |
| 3 | Collier County, FL | 2007 | 30" DR 25 | 1100 ft | Y | **Y** |
| 4 | Greencastle, IN | 2007 | 10" DR21 | 800 ft | Y | **Y** |
| 5 | Greencastle, IN (2) | 2007 | 10" DR 21 | 43 ft | Y | **Y** |
| 6 | Pittsburgh, PA | 2007 | 24" DR 25 | 160 ft | Y | N |
| 7 | Clay County, FL | 2008 | 20" DR18 | 600 ft | Y | **Y** |
| 8 | Clay County, FL | 2008 | 20" DR 18 | 1600 ft | Y | **N** |

| | | | | | | |
|---|---|---|---|---|---|---|
| 9 | Xenia, IA | 2008 | 20" DR 18 | 1100 ft | Y | **Y** |
| 10 | Tampa, FL | 2009 | 8" DR 25 | 200 ft | Y | N |
| 11 | Baton Rouge, LA | 2009 | 36" DR 32.5 | 300 ft | Y | **Y** |
| 12 | Baton Rouge, LA | 2009 | 24" DR 25 | 900 ft | Y | **Y** |
| 13 | Collier County, FL | 2010 | 30" DR 25 | 750 ft | Y | **Y** |
| 14 | Chatham, IL | 2011 | 18" DR 25 | 850 ft | Y | **Y** |
| 15 | Fremont, CA | 2011 | 12" DR 25 | 2000 ft | Y | **Y** |
| 16 | Green Bay, WI | 2011 | 16" DR 18 | 300 ft | Y | N |
| 17 | Salt Lake City, UT | 2012 | 16" DR31 | 350 ft | Y | **Y** |
| 18 | Salt Lake City, UT | 2012 | 16" DR31 | 3300 ft | Y | **Y** |
| 19 | Dorchester County, SC | 2012 | 20" DR 21 | 2200 ft | Y | **Y** |
| 20 | Watford City, ND | 2013 | 16" DR 21 | 850 ft | Y | **Y** |

Based on these examinations, it is clear that there are multiple examples of false and misleading statements in Palermo's list of RCP failures:

**No. 3 Collier County, FL** – I conducted a site inspection at Collier County in January, 2007 and conducted laboratory testing of pipe from the incident, as outlined in a report to UGSI in 2007 [2] and a published paper at the Society of Plastics Engineers (SPE) Annual Technical Conference (ANTEC) in 2010 [1]. The following points can be made regarding the cause of the failure in Collier County:

- The contractor failed to correctly install the mega-lug endcaps onto the pipe – they did not tighten the bolts properly. Proper installation of the mega-lug endcap requires tightening of the bolts until the top portion of the bolt shears off as it is designed to do. This lack of tightening caused the endcap to slip and initiate through-wall cracks in the fusible PVC pipe.
- The contractor failed to remove air from the pipe for the test. The only air vents were at the center of the endcaps, making it impossible to remove the air completely. This left air at the south end where the fracture originated and trapped a large portion of air at the far end (north end) of the pipe. The pipe had been pulled under an expressway and up on the north side where approximately 100 feet of pipe was laid out on the ground. The north end was a high point in the system and due to the layout of the pipe and venting from the center of the endcap trapped approximately 150 cubic feet of air (prior to pressurization) at this end.
- The contractor ignored clear signs that there was a lot of air in the pipe. Normally, it only takes a few minutes to get a pipe up to test pressure if all of the air has been removed. In this case it took over 20 minutes to get the pipe up to pressure.
- The contractor conducted the test in an unsafe manner, endangering the lives of those working around it. ASTM specifications for all plastic piping (including PVC, ABS, and HDPE) have warnings against pressurizing pipe with air due to inherent safety issues.
- The failure of this pipe was not a service related failure and occurred due to gross negligence by the contractor. If the endcaps had been properly installed, the failure would not have occurred. If the air had not been trapped in the pipe, the failure, if it occurred, would have been very limited.
- Palermo's slide 4 is misleading by not providing any information regarding the cause of failure.

**No. 4 Greencastle, IN** – I conducted a site inspection on 8-15-07 and a later laboratory inspection of pipe samples from the incident, as outlined in an ESI report to UGSI dated 9-14-07. The pipe had been pulled into a cast iron pipe that was more than 100 years old. The following points can be made regarding the cause of the failure in Greencastle, IN:

- The crack initiated at a hot tap. The crack traveled approximately 30 feet from the hot tap location to an insertion pit where the crack arrested at a metal coupling. The crack also traveled approximately 400 feet in the opposite direction, arresting in a straight pipe section across the road.
- The total crack length was approximately 430 feet and not the 800 feet listed in Palermo's presentation.
- The cracking occurred due to initiation at a poorly executed hot tap and propagated due to locked-in bending stresses present in the fusible PVC pipe inside of the host cast iron pipe.

**No. 5 Greencastle, IN** – I conducted a site inspection on 8-31-07 and later laboratory inspection of pipe samples from these incidents, as outlined in an ESI report to UGSI dated 9-14-07. The following points can be made regarding the cause of the failures in Greencastle, IN:

- The crack length was actually 30 feet (and not the 43 feet reported by Palermo) and occurred during a hot tap operation. The cracking in this pipe was typical of a poorly done hot tap procedure. This failure likely would not qualify as an RCP failure.
- The material at the hot tap location was heated enough to cause melting and flow of the material, leading to fracture.
- Bending stresses contributed to the cracking in the pipe, as evidence by the pipe heaving upward approximately 3 inches after the fracture occurred.

**No. 7 Clay County, FL** – I attended a site inspection on March 18, 2008 to examine the fractured pipe and select samples for laboratory analysis. The cause of the failure was a saw cut of a section of pipe that was bent. This pipe was not pressurized at the time of failure. The following points can be made regarding the cause of the failure in Clay County, FL:

- The pipe section fractured over 30 feet from a saw cut, arresting near the endcap that was in place for the previous successful pressure test.
- The crack went an unknown distance into the ground. A 6 to 8 foot section was removed after additional excavation. There was a partial crack that mated to the pipe still in the ground that likely was close to arresting. The total length of cracked pipe, though not known precisely, is likely to be a total of 40 to 60 feet, based on what was observed at the inspection and not the 600 foot long crack listed in Palermo's table for item 7.

**No. 9 Xenia, IA** – I attended a site inspection of this pipe on August 19, 2008 near Des Moines, IA to view the installation area and inspect several pipe sections that were excavated from the failed area. Pipe samples were also selected for laboratory testing that occurred at a later date at ESI. The fracture occurred during a pressure test with the cracks traveling more than 120 feet. The following points can be made regarding the failure in Xenia, IA:

- The extensive crack branching indicates that there was air present in the pipe at the time of failure.
- There were reported problems with the pipe getting stuck, having to remove it, re-drill and pull it in again.
- There was evidence of damage to the fusion bead that likely occurred when the pipe got stuck.
- The fracture origin was not found in the sections of pipe that were retained.
- The total length of the crack in the pipe is unknown.

**No. 11 Baton Rouge, LA** – Pipe from this fracture was examined at UGSI in Cranberry Township, PA on December 10, 2009. The following points can be made regarding the failure of this pipe section:

- A joint crack (~3 feet long) was approximately 300 feet from the end of a 1600-foot pipe string – not a 300 foot crack, as cited by Palermo in his table.
- The pipe was not under pressure and was not installed at the time of the fracture – not an RCP failure.
- The fracture initiated at or near a fusion where the pipe was being pulled along and over metal rollers.
- The fracture origin was a ductile overload, indicating that it had been stressed in excess of the pipe materials yield strength, likely due to localized impact/bending of the pipe due to improper tailing of the pipe by the contractor causing the pipe to come off of the rollers and impact the fusion equipment.

**No. 12 Baton Rouge, LA -** Pipe from this fracture was examined at UGSI in Cranberry Township, PA on May 20, 2009. The following points can be made regarding the failure of this pipe section:

- The near end of the pipe was fractured during a saw cut operation and was not under pressure at the time of the failure – not an RCP failure.
- The crack propagated to a larger extent from the saw cut due to point loading ~16 inches from where the saw cut was made. The pipe had two localized failures and was not a continuous crack.
- The presence of additional locked-in stresses caused the crack to propagate an unknown distance into the pipe.
- The cracking pattern indicates that additional unknown stresses were involved in the pipe fracture.
- Significant torsional stresses likely occurred due to installation methods or equipment during the pull-in operation.
- The fracture at the far end of the pipe was due to extreme bending from a mega-lug fitting that was apparently used to lift and/or pull the pipe.

**No. 13 Collier County, FL** – I attended two site inspections on March 4, 2010 and March 16, 2010 at the site of the pipe failure (March 4$^{th}$) and later (March 16$^{th}$) at a holding facility for pipe removed from the failure site.

- The fracture occurred due to intense point loading from large rocks underneath the pipe in the trench.
- There was a large amount of air present in the pipeline at the time of the failure, leading to extensive cracking.
- Air release valves were improperly sized and were not functioning, causing a large amount of air to be in the pipe.

- A report by Malcolm Pirnie, dated April 2010 [4], also details the many installation and operational errors that lead to the failure.

**No. 14 Chatham, IL** - I attended a site inspection of this pipe on May 5, 2011 in Rochester, IL. The pipe was part of the Chatham Water Municipality. The following pints summarize the failure of this pipe:

- The pipe cracked during a pressure test that occurred 6 months after the HDD installation of the pipe through a rock formation. The crack length was approximately 876 feet.
- The fracture origin occurred at approximately 300 feet from the pit near the pull end of the installation.
- The pipe fracture appeared to have initiated at a butt fusion, based on a video inspection of the pipe.
- The crack branches and spirals away from the origin area, apparently due to very high bending and torsional loads.
- A review of point-to-point elevation maps of the pipeline show multiple severe bends that were much smaller (as low as 23 to 49.5 feet) than the minimum bend radius for the pipe of 406 feet. This resulted in extremely high bending stresses that lead to the failure.
- Slide 28 contains limited information on the Chatham, IL incident and has the same problem as the table in Slide #3. Palermo ignores all the other factors beyond internal pressure that existed which contributed to the events (detailed above).
- In slide 28 Palermo also calculates $P_c$ using the outdated information in the 1995 Greenshields paper [11]. If one views this with the knowledge that the critical pressure of Fusible PVC pipe will be far higher than what he presents in his slide, then it is clear that other factors beyond internal water pressure had to have contributed. The misrepresentations here are many, including not providing all information that was available to him, including ESI reports, published papers in 2010 by ESI and by UGSI, use of 10 percent air as a normal operating condition to calculate full scale $P_c$ values for the involved pipes.

**No. 15 Fremont, CA** – I attended a site inspection at Solyndra in Fremont, CA on April 27 – 28, 2010. Additional visits were made to a contractors lot in Mipitas, CA and at Exponent, in Menlo Park, CA to further inspect pipe removed from the failure location. Additional laboratory examination of samples was also performed at ESI in Aurora, IL at a later date. The following observations were made regarding the failure of the Solyndra pipe:

- The cracking in this pipe totaled approximately 200 feet, consisting of several smaller cracks, and not the 2000 feet listed in Palermo's item 15 in his table.
- The initial area of the failure comprised 30 to 40 feet of pipe that blew apart when an improperly attached fitting gave way and the pipe exploded due to large volumes of air trapped at that location.
- An adjacent section of pipe cracked inside-out due to a momentary vacuum surge in the pipe that occurred when the adjacent pipe section blew apart. This crack encountered another air-filled section of pipe that also blew apart when the crack reached the air pocket.

**Nos. 17 and 18 Salt Lake City, UT** – I attended a site inspection near Salt Lake City on April 30, 2012 to observe the pipe failure areas that occurred in part of the Southwest Jordan Valley Groundwater Project. The following observations were made related to the failure of the pipe:

- Large amounts of air were entrained in the pipe at the time of the failures.
- The pipeline was improperly operated at very high velocities during pigging operations.
- Lack of control of piping system, causing large pressure surges due to venting pockets of air.
- 7 miles of pipe were replaced and not the 13 miles cited in Palermo's slide 13. There were 7 miles of fusible PVC pipe installed, based on the drawings of the pipe system. The water municipality did not replace 13 miles of pipe.

**No. 19 Dorchester County, SC** – I attended a site inspection on May 31, 2012 at a pipe HDD installation in Summerville, SC. The following observations were made related to the failure of this pipe:

- The failure occurred during a pressure test of the installed pipe.
- A video inspection was done from the west end where the fracture ended. The camera could only be inserted approximately 480 feet into the pipe and showed that cracks were still proceeding towards the west (south) end at this point. It was not possible to get the camera further into the pipe to observe the origin of the fracture.
- The pipe installation was approximately 2200 feet in length. The actual crack length is unknown, since the origin and the opposite end of the crack (under the creek) were not observed. The crack length is significantly less than the 2200-foot crack length cited by Palermo in Item 19 of his table.
- The crack is at least 450 to 500 feet less than the 2200 feet that was installed, since the pump was inserted approximately 500 feet into the pipe at the uncracked end.
- Very little was learned about the cause, since the fracture origin was never located or recovered.
- There were reports of a gunshot hole in a section of a pipe that was used on the project. It is possible that the pipe was installed with pre-existing damage.
- Slide 29 contains limited information on the Dorchester County, SC incident and has the same problem as the table in Slide #3. Palermo ignores all the other factors beyond internal pressure that existed which contributed to the events (detailed above).
- In slide 29 Palermo also calculates $P_c$ using the outdated information in the 1995 Greenshields paper [11]. If one views this with the knowledge that the critical pressure of Fusible PVC pipe will be far higher than what he presents in his slide, then it is clear that other factors beyond internal water pressure had to have contributed. The misrepresentations here are many, including not providing all information that was available to him, including ESI reports, published papers in 2010 by ESI and by UGSI, use of 10 percent air as a normal operating condition to calculate full scale Pc values for the involved pipes.

**No. 20 Watford City, ND** – I examined pipe from this failure at ESI in April, 2013 and reviewed photographs of the installation and failure site. The following points relate to the failure:

- The failure was due to extreme overbending of the fusible PVC pipe into the bell of another AWWA C905 PVC pipe that caused water to leak past the gasket and erode the fusible PVC pipe.
- 96% of the pipe wall for the fusible PVC pipe was eroded away prior to fracture.

- The actual length of the crack is unknown, but Palermo's stated length of 850-foot length of the crack is also likely wrong, as the pipe exhibited multiple areas of damage due to excavation and removal.
- Palermo's photograph in slide 13 gives no information as to the cause of the failure.

Dr. Palermo provides no information or relevant data that would bear on the root cause of why the incident in each row of his table occurred. None of the information obtained by ESI in actual failure investigations is included by Palermo because he has not conducted any analysis. His implication in doing this is to make the reader/observer believe that the only reason for each incident was that the pipe involved was Fusible PVC. He does not provide information on installation conditions (like pipe bending, internal pressure, trapped air in the line, etc.) In contrast ESI was directly involved on site in many of these cases and was able to conduct an analysis of the failures that included this information.

In slide 15, Dr. Palermo has three bullet points, the first of which has a sub bullet point associated with it. The sub-bullet says, "*For RCP to occur there must be an initiating event such as a field induced crack*." There are two things unsaid here that deserve mention. First, he mentions only one specific contributor to the "initiating event, that being a "field induced crack." This implies that Fusible PVC pipe is not sufficiently durable to tolerate any kind of installation upsets like the minor scuffs and scratches that occur during directional drilling or even open trench installation. No mention is made of installation issues that can be far larger contributors to an RCP "initiation event" like improper installation of fittings, excessive bending of pipe, trapped air, etc. Second, no further mention is made in this entire presentation about the "initiating event." The focus is entirely on what happens (or doesn't happen) after the "initiating event" is done. No mention is made anywhere in this presentation that if one does the necessary things to avoid an "initiating event" then RCP does not occur.

In Slide #16, the dynamic fracture toughness of 0.64 kJ/m$^2$ is apparently taken from the 1995 Greenshields & Leevers paper, [11] which involved testing on PVC pipe with significantly inferior properties to those of Fusible PVC. The lower quality of this pipe that was tested by Greenshields and Leevers was known in the industry and was cited as a reason for the many early field problems with this pipe. [11] Another comment on his first bullet point here is that it again ignores what it takes to initiate an RCP event and focuses only on what happens after the avoidable initiating event occurs.

Palermo also states in this slide that PVC is, "..more susceptible to crack initiation". That statement is simply not true. The value of $G_D$ (which he incorrectly assigns to Fusible PVC) does not relate to the resistance to crack initiation, but is a measure of the crack arrest toughness after a crack has already occurred. In general, it takes larger forces to initiate a crack in PVC than it does for HDPE due to PVC's higher strength and stiffness, making PVC more resistant to crack initiation than HDPE. If one looks into the early PVC brittle failures in Europe, one finds that most of them were caused by the use of very poor PVC material and poor installation methods, along with air entrainment and excessive surge pressures [15]. The poor quality material that was encountered in these cases lead to the establishment of requirements for minimum levels of fracture toughness for PVC, and these requirements were included in pipe standards [16]. The idea was that if the pipes were made tougher, there would be less incidences of crack initiation in the field and this has been borne out in experience.

There are several factors that are critically important in order for RCP to occur in Fusible PVC pipe. These include:

- Internal pressure in the pipe
- Exposing the pipe to extremely high localized stresses such as severe bending stresses, point loading, impact, etc.
- Improper installation of the pipe
- Failure to remove air from the system or operating a pipe with large amounts of air
- Improperly securing fittings to the pipe
- Improper cutting or tapping of the pipe

Following proper installation and use practices is the best way to prevent RCP in any pipeline. In a properly installed and operated Fusible PVC water pipe system, RCP will not occur. This is contrary to the message that Palermo has made in his presentations on the subject.

In Slide #21, the S4-to-Full Scale correlation equation is the one developed by Greenshields & Leevers for PE pipe. This is the equation that is in the ISO standard (ISO 13477) [26] and for the purposes of the standard is applied to all materials. This equation has been stated to be material-independent by Dr. Palermo when, in fact, the equation simply does not take material of any kind into account. The equation is based on gas dynamics or how compressed gas flows out of a cracking pipe. Dr. Palermo should have disclosed in this presentation that the correlation equation has not been universally accepted as applicable to all materials.

Palermo's slides 22 and 23 are blatantly false and misleading. First of all the curve connecting the points on the graph is not a curve at all, but is a couple of separately drawn lines through the data points. The discontinuity in the "curve" is not a valid presentation of the data. In slide 23, he chooses the worst possible condition for calculating $P_c$ for PVC pipe by taking the value for >10% air developed in the 1995 Greenshields work. He claims this value is 1.6 bar, when actually the 10 percent air value is 2.3 bar. Palermo grossly misuses the data by taking an unrealistic condition (> 10% air) for his example calculation that is not typical of water pipe systems and is specifically warned against in industry standards, installation guides and operating guides. He calculates a $P_c$ that is only slightly more than half of the operating pressure, which is a gross misrepresentation of the facts.

Palermo's selection of 10 percent air as a typical situation that is encountered in water systems is blatantly false, misleading and dangerous. The basic premise for this "rating" of Fusible PVC pipe is based on an incorrect choice of 10 percent air as the environment to use Fusible PVC pipe (or any water pipe, for that matter). Water pipes should be used without any air in them. It is true that there may be low levels of air in pipes, as it can be difficult to get all of the air out, but the typical value in water distribution piping would be much less than 2 percent. Operating at higher levels of air is potentially dangerous for any pipe material. A specific warning about the dangers of air in plastic pipe is included in Section 9.4 of ASTM F2164-02, *Standard Practice for Field Leak Testing of Polyethylene (PE) Pressure Piping Systems Using Hydrostatic Pressure*. Section 9.4 states, "Filling - Fill the test section slowly. Purge all air. Take all appropriate precautions to ensure that no air is trapped in the test section. (**Warning** – Entrapped air can result in an explosive, violent, and dangerous catastrophic failure because both the pressure stress on the piping and the energy used to compress the entrapped air are released.)" [3].

If one takes the value for 2% air off of the graph in Slide #22, which appears to be 3.8 bar, then the $P_c$ (FS) value using the Greenshields & Leevers correlation equation comes out to be 236 psig, which is greater than the incorrect 222 psig working pressure Palermo cites in Slide 23.

The rated pressure for the PVC pipe that was tested by Greenshields and Leevers was 12 bar (174 psig), as specified in British Standard, *Specification for Unplasticized Polyvinyl Chloride (PVC-U) Pressure Pipe for Cold Potable Water*, BS 3505:1986. This was specifically acknowledged in the Greenshields and Leevers papers as well. [9, 10, 11] Palermo incorrectly re-assigns a higher number to the rated pressure based on using an HDB value for U.S. PVC pipe (AWWA C-900 pipe) for which the older European PVC pipe material did not qualify for, of 4000 psi. Use of this HDB value leads to the wrong pressure rating stated in his presentation of 222 psig, a value that is 27.6% higher than the actual rating for the pipes tested.

The use of an inflated pressure rating and using the wrong value for 10 percent air from the Greenshields and Leevers paper allows him to say that the critical pressure for the PVC pipe is only slightly more than half of the operating pressure, even though both of his numbers are grossly in error. Even if he used the 10 percent air value of $P_c$ in the Greenshields and Leevers paper (2.3 bar), which is not typical of proper pipe installation and use, and the actual pressure rating of the pipe tested, the critical pressure would be close to the rated pressure. In this case, using the 10 percent air value of 2.3 bar results in a calculated full-scale critical pressure of 158 psig, which is only slightly lower than the 175 psig, the actual rated pressure of the pipe tested and not slightly over half of the rated pressure as shown by Palermo.

However, the value that should be used is zero percent air, or at the most, less than 2 percent air, which is more typical of actual water pipe systems in the field. The 2 percent air value for the pipe tested by Greenshields and Leevers is 3.8 bar, which calculates to a full-scale critical pressure of 16.28 bar or 236 psig, which is greater than the actual rated pressure of 174 psig and even is greater than the incorrect pressure rating of 222 psig that Palermo claims for the PVC pipe in his presentation.

In Slide #30, he has a quote attributed to Greenshields & Leevers but doesn't give the complete citation for its source. [13] The first bullet point in Slide #31 is incorrect in light of most of the criticisms noted above. It is clear that proper installation and testing of the pipe would have eliminated the initiation of cracks in these incidents and thus eliminated an RCP event. His only "design" recommendation is to use PE 4710 pipe, since there is no standard for PVC pipe below DR14. Again, the calculation used to come up with the DR13 statement relies upon utilizing the wrong test conditions (10 percent air), an inferior grade of PVC, and a heavily modified, non-standard S4-type test conducted by Greenshields and Leevers.

Slide 31 purports to give design advice, but fails to address the cause of the RCP failures and fails to include any information regarding how to avoid initiation of these failures. It is clear that, from a design standpoint, proper installation, assembly, testing and operation of any pipeline is of utmost importance. Elimination of air is important to eliminate many of the failures that occur due to pressure surges caused by air pockets, but more importantly allow piping systems to be used safely. Dr. Palermo's statements in his presentations and in deposition claim that 10 percent air is a normal consequence of operating a water pipeline. This is absolutely not the case and it is a very reckless position to promote in the industry, as he does.

Contrary to what Palermo claims, Fusible PVC is not susceptible to RCP in 100% water when operated under normal conditions. Many things have to go wrong in order for RCP to occur including:

1. overstressing of the pipe from bending initiation or other source
2. improper assembly of fittings
3. improper installation of pipe
4. presence of large amounts of air in pipe
5. large pressure surges

Slide 32 contains some of Palermo's recommendations, based on what he has presented. His recommends that Fusible PVC should be tested to determine the S4 and full-scale critical pressure and to determine the effect of pipe size and DR. This suggests at a minimum the recognition that the data he had just presented is inadequate and does not correctly describe the use of Fusible PVC in a water system. He goes on to recommend in slide 33 that the DR of Fusible PVC pipe be limited to less than DR13 if the full-scale critical pressure is not known. Again, this recommendation is based on the false and incorrect analysis that he has set forth in his presentation.

In slide 34 Palermo concludes with false statements, stating that RCP is impossible for water-filled PE pipe and falsely claims that test results and field experience indicate that the critical pressure for PVC pipe (and by implication Fusible PVC pipe) is less than the rated pressure. The sole basis for his conclusions in his presentation are the fundamentally flawed findings regarding performance of PE versus PVC in modified S4 RCP tests. He does not cover at all any other design and operational issues that should be employed for any pipe material, including polyethylene, that would eliminate RCP failures in service. These issues include removal of air in the pipes, limiting excessive pressure surges in the pipes and following standard installation practices, testing and operation of the pipes. He compares PE pipe of a much lower dimension ratio to PVC and uses modified S4 test results to attempt to indicate a risk of RCP in the field. His citation of field experience is also in question since he did not conduct any investigations in to the failures in his table.

## Discussion

The Palermo reports and presentations reference several papers and publications on RCP by Greenshields and Leevers [8-13]. It is important to put these test development publications into perspective and analyze what these papers say about RCP in plastic pipes and what they do not say. The following discussion will point out essential facts about the RCP failures of PVC butt-fused pipe and will also point out the distortion (by Palermo) of the results set forth in publications by Greenshields and Leevers, et al. [8-13].

It is acknowledged in a journal article by Greenshields and Leevers that the PVC-u pipe that was tested is from earlier grades of pipe that may not perform as well as current PVC pipe [11,14]. The article also references work that shows that most of the early RCP failures in Britain were attributable to sub-standard pipe material and to improper installation and operating conditions [15]. Palermo implies by his use of the testing of European PVC pipe in the early 1990's that the UGSI pipe is functionally the same as that tested by Greenshields and Leevers so that he can claim that the data in the Greenshields and Leevers papers apply to the UGSI heat-fusible pipe. However, there are literature citations concerning the inferior properties of this pipe and Palermo himself has knowledge that AWWA pipe has superior properties compared to the early 90's European PVC pipe.

The UGSI formulation also has higher fracture toughness than typical PVC pipe resins. A fracture toughness test was included in a British standard for PVC-u water pipes, that applied a stress intensity to the pipe specimens of 3.25 MN-$m^{3/2}$ (2.96 ksi-$in^{1/2}$), establishing a minimum fracture toughness that was allowed for PVC-u pipe in water applications. This fracture toughness test is part of BS 3505: 1986, *British Standard Specification for Unplasticized Polyvinyl Chloride (PVC-U) Pressure Pipe for Cold Potable Water* [16]. The fracture toughness of PVC has also been reported to range from approximately 2.0 to 4.0 MN-$m^{3/2}$ (1.8 to 3.6 ksi-$in^{1/2)}$ at 20$^o$C [17] and an average $K_{IC}$ value for PVC pipes of 3.04 MN-$m^{3/2}$ (2.77 ksi-$in^{1/2}$) was reported for PVC pipes in 1982 [18]. The UGSI pipe has a fracture toughness of 4.12 ksi-$in^{1/2}$, measured at -40$^o$C [19], approximately 14.4 percent higher than the highest previously reported value of 3.5 ksi-$in^{1/2}$, and approximately 48 percent higher than the average value for PVC-u pipe [16-18]. The importance of this is that the UGSI pipe will have a greater resistance to initiation of a crack that could lead to RCP under extreme conditions.

Palermo claims that RCP can occur in applications of butt-fused PVC pipe with water (no air) by associating it with heavily modified S-4 tests on PVC-u pipe that were described in several papers in the 1990's by Greenshields and Leevers [8-14]. The modification to the S-4 test by the authors of that study was intended to further limit the decompression of the pipe that normally occurs when a pipe fails, maintaining the driving force for continued crack propagation. A model that was used by Greenshields and Leevers in these early publications is the Irwin-Corten model for rapid crack propagation. The authors of the journal papers themselves point out that the model is not valid for any testing other than the case of water-only and is not valid for inclusion of air in the system. Current articles and presentations by Dr. Leevers state that the Irwin-Corten analysis is not sufficient to describe RCP in plastic piping and, in particular, is not sufficient to describe the S4 and modified S4 testing of plastic piping. Dr. Leevers writes, "Analytical models have been – like that of Irwin and Corten – too simple and schematic to account for factors in play" [8]. He also states, "The FS test [full-scale] retains gold-standard status through its truth to service conditions". The fact that Dr. Palermo did not acknowledge this shortcoming of the analysis of modified S4 testing by Greenshields and Leevers shows that his presentations are misleading. Palermo appears to accept the testing as reflecting actual pipe installations, while the authors of the study acknowledge that it does not.

The statement that water-only RCP failures are straight and that air-water or air RCP failures are sinusoidal, is an observation that has generally been made for failures generated in modified S-4 tests, but are not indicative of all of the failures in these tests and certainly not for RCP full-scale and field failures. The appearance of these fractures is not well understood, as commented by Leevers, et al., "*The importance of this phenomenon is probably much less than the interest it excites. A crack which describes sinusoidal oscillations around a straight path would be expected to demand more energy, and therefore to require a higher critical pressure. However, conservative assessment of critical pressure in this case would have to assume a straight path, and this, for computational simplicity, is what is always done. No complete and testable model for the sinusoidal crack path has yet been offered.*" [10]. Dr. Leevers, at his RCP paper presentation at SPE ANTEC on May 3, 2011, declined to comment on the cause of the appearance of the cracks that result from RCP failures [8]. It appears that many factors enter into whether the crack is straight, curving or sinusoidal in nature, including the material and structure of the pipes, applied stresses in the pipes, the local speed of the crack, the energy dissipated during the fracture event, residual stresses and the initial impact energy. Differences in the initial energy of the striker caused different fracture appearances as shown in Figure 7 of Reference 11. A figure in a Chevron-Philips presentation on RCP shows a failure in PE pipe that is initially straight and then is somewhat sinusoidal before arresting in the

pipe, suggesting that crack energy, or speed may affect the crack appearance [22].

Palermo states in the slide entitled “Preventing Rapid Crack Propagation in PE Pipes” [7] that, “The best way to design against a Rapid Crack Propagation occurrence in PE Pipe is to select a PE material that has high resistance to RCP”. While material selection may be one aspect of design, there are many considerations when choosing a material for an application. It is much more efficient to eliminate the specific causes of RCP in pipes (plastics and metal); eliminate entrained air, utilize proper installation methods, use proper test procedures, and use proper operating procedures.

He also states in this slide that RCP will never occur in PE 4710 pipe. There is no evidence to back up this statement. RCP failures have occurred in PE100 water pipe (European equivalent of PE 4710) due to an oxidized inner surface. [24] There also are many other examples of RCP failures in PE80 materials. The RCP failures of polyethylene pipe in these cases also occurred due to extremely poor care in installing and operating the pipes and RCP would have been prevented if a normal standard of care had been used.

The S4 test results by Greenshields and Leevers do show that PE100 materials are very resistant to RCP, but this statement ignores the fact that the inner surface of PE pipes can and will be oxidized during long-term potable water exposure. No one to our knowledge has performed hydrostatic S4 tests of any kind on PE pipe that has an oxidized inner surface. The importance of this is that several of the Greenshields and Leevers papers [10,11] point out that the ductile inner layer in PE pipe RCP failures likely contributes significantly to the higher critical pressures that are measured. They have demonstrated this by testing internally notched specimens that do exhibit a lower critical pressure. An oxidized inner surface would introduce a very sharp crack and may have a dramatic effect on the RCP performance of the pipe, as shown by the RCP failure of an oxidized PE 100 pipe [24]. Dr. Leevers himself, when asked during his ANTEC 2011 presentation what effect an oxidized layer would have on the RCP resistance of PE, stated that “very bad things would happen” [8]. PVC pipe materials are not affected by disinfecting agents that are added to potable water. Research in Europe has shown that the lifetimes of PE 100 in potable water is, in some cases, less than that for PE 80 due to the action of chlorine and chlorine dioxide [25].

Palermo notes that, “Care needs to be taken to avoid impact, tapping, or other damage to fused PVC pipelines.” This statement can and should be applied to all piping including polyethylene and metal pipes. If a normal standard of care is used in the installation, testing and operation of butt-fused PVC pipelines, or any other pipeline material, RCP will not occur.

## Conclusions

The following conclusions/opinions are held within a reasonable degree of engineering certainty. I reserve the right to change or augment my opinions if additional information becomes available that warrants it.

**Opinion 1**: RCP failures in butt-fused PVC pipe are rare and have only occurred in circumstances that are well outside of normal operations and could easily have been avoided by applying a normal standard of care in the testing and/or installation and operation of the pipelines. Dr. Palermo's presentations distort this fact and presents RCP in butt-fused PVC as a problem waiting to happen.

**Opinion 2:** The suggestions that fusible PVC pipes are inherently susceptible to RCP at pressures below their static pressure rating are false. Dr. Palermo utilizes numbers in his calculations that he knows are wrong in order to make the statement that the critical pressure for butt-fused PVC is below the rated pressure.

**Opinion 3:** The presence of air in water piping systems represents a danger to any piping system and must be accounted for and eliminated. Dr. Palermo states that 10 percent air in a water piping system is normal. He states this in his presentations and in deposition testimony. This is a reckless position to take since entrained air in a pipeline is warned against in many industry standards and is recognized as a danger, both to the piping system and to the public.

**Opinion 4:** Dr. Palermo relies upon misrepresentations of the findings from the Greenshields and Leevers publications [8-14] to support his flawed and unsubstantiated recommendations to use only PE4710 pipe to avoid RCP, and to give his presentations and papers a false impression of being scientifically valid.

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-End of Report Text -

# APPENDIX I

## CV of Dale B. Edwards, P.E.

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**DALE B. EDWARDS, P.E.**
**SENIOR MANAGING CONSULTANT**
**dbedwards@engsys.com**

Mr. Edwards is a polymer materials scientist with over 35 years of experience in the plastics and composites industry. He is a co-author of the book, **Fractography in Failure Analysis of Polymers** that was published in 2015. His experience includes testing and analysis of plastic, rubber and composite materials, consulting, and laboratory management. He has special expertise in failure analysis, fractography and testing of plastics, including plastic pipe and fitting materials and stress rupture testing for design. Additional expertise includes failure analysis, creep and stress rupture, fracture, mechanical testing, analytical testing, environmental effects and lifetime prediction. Mr. Edwards has managed a polymer test laboratory (Bodycote Broutman) that included hydrostatic pipe testing, mechanical and analytical testing of polymers and composite materials. Mr. Edwards has taught courses on failure analysis, fracture of plastics and testing of plastic materials and has provided expert testimony regarding product failures in both state and federal courts.

## Areas of Specialization

Failure analysis and testing of plastics, including plastic pipe and fitting materials
Stress rupture testing for design
Failure analysis
Creep and stress rupture
Fracture
Mechanical testing
Material Selection
Environmental effects and lifetime prediction

## Education

B.S. Chemical Engineering - University of Illinois, 1978

Graduate Courses in Materials Engineering - IL Inst. of Technology, 1981-1982

## Licensed Professional Engineer (P.E.)

IL (062-041364)

October 2015

## Professional Affiliations and Honors

Society of Plastics Engineers (SPE) – Senior Member

- Technical Program Chair – Failure Analysis and Prevention Special Interest Group (FAPSIG), 2010-2011
- Chairman – FAPSIG, 2011, 2012
- Dr. Myer Ezrin Best Paper Award – ANTEC 2011
- Member of the Board of Directors of the Medical Plastics Division of SPE (2007 through 2010)

American Society for Testing and Materials

Member of Committee F-17 on Plastic Piping Systems

Peer reviewer for the Journal of Pipeline Systems

## Positions Held

Engineering Systems, Inc., Aurora, Illinois

Senior Managing Consultant, 2010 to Present
Senior Consultant, 2007 to 2010

Bodycote Polymer-Broutman Laboratory, Chicago, Illinois

Senior Consultant, Bodycote Polymer, 2004-2007
Vice President, Technical, Bodycote Polymer, 2000-2004

Bodycote Broutman, Inc., (f.k.a. L.J. Broutman & Associates, Ltd.)

Vice President, Plastics Technology, 1995-2000
Manager, Piping Products Laboratory, 1990-1995
Research Engineer, 1982-1990

International Harvester Company

Research Associate, 1979-1982

## Teaching

Mr. Edwards has taught seminars in the Plastic Failure Analysis Series that were co-sponsored by The Society for Plastics Engineers (SPE):

"Plastics Failure Analysis/Prevention and Testing Seminar" (1995-2001, 2007, 2008), Failure Analysis Seminar Series sponsored by Bodycote Broutman, Inc. and the Society of Plastics Engineers. This seminar is also being presented by Mr. Edwards and his colleagues at ESI, starting in 2015.

"Mechanical Properties of Polymers and Service Life Predictions" (1995-1999) Mechanical Behavior of Plastics Seminar Series sponsored by Bodycote Broutman, Inc. and the Society of Plastics Engineers

"Plastics Fracture Analysis Workshop" (2001-2008) Failure Analysis Seminar Series sponsored by Bodycote Polymer – Broutman Laboratory and the Society of Plastics Engineers. This seminar is also being presented by Mr. Edwards and his colleagues at ESI, starting in 2015.

Mr. Edwards has taught seminars on failure analysis of plastics for medical devices, co-sponsored by the Medical Plastics Division of SPE:

"Failure Analysis of Plastic Materials for Medical Devices: A Tool for Prevention"
The Medical Design and Manufacturing Conference, MDM West, Anaheim, California, January 2004
MDM East, New York, June 2004
MDM Midwest, Minneapolis, Minnesota, October 2004
MEDTEC, Stuttgart, Germany, March 2006

"Failure Analysis of Plastic Materials – A Tool for Prevention", presented at Design & Manufacturing Midwest 2010 Conference, Rosemont, Illinois, September 29, 2010

Mr. Edwards has also taught a seminar as an adjunct instructor at Lewis University titled "Manufacturing Processes for Composite Materials," December 17, 2011

## Additional Training

Infrared Microscopy Course (FTIR spectroscopy), Hooke College of Applied Sciences (McCrone Group), April 20-22, 2010

Strategy of Experimentation – DuPont Specialty Services Course, June 1987

## Book Contribution

**Fractography in Failure Analysis of Polymers**, M. D. Hayes, D. B. Edwards, A. R. Shah, Elsevier Inc., Oxford, UK, 2015

## Publications

"Determining the Processing Quality of PVC Pipe by DSC – How Precise?" Proceedings of the 17$^{th}$ Plastic Pipes Conference, PPXVII, Chicago, Illinois, September 22-24, 2014, with D. E. Duvall and A. R. Shah

"Assessment of Polybutylene Plumbing Installation after 18 Years of Service," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Cincinnati, Ohio, April 22-24, 2013, with D. E. Duvall

"Polybutylene Water Service Pipe: The Other Side of the Story," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Orlando, Florida, April 1-4, 2012, with D. E. Duvall

"Determination of Environmental Stress Cracking Failure Mode in Investigation of CPVC Fire-Suppression Sprinkler Pipe Failures," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Orlando, Florida, April 1-4, 2012, with A. R. Shah

"Failure Analysis of Plastic Crimp Fitting Assemblies," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Boston, Massachusetts, May 1-5, 2011, with D. E. Duvall and A. R. Shah

"Field Failure Mechanisms in HDPE Potable Water Pipe," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Boston, Massachusetts, May 1-5, 2011, with D. E. Duvall

"Challenges in Investigating Chlorinated Polyvinyl Chloride Pipe Failures," Journal of ASTM International, 8(1), 2011, with M. D. Hayes, M. L. Hanks, F. E. Hagan and D. E. Duvall

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"Evaluation of Fractures Created in Plastic Pipes by Freezing of Water Inside of the Pipes," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Orlando, Florida, May 16-19, 2010, with D. E. Duvall and J. F. Grzetic

"Analysis and Testing of Freezing Phenomena in Plastic Piping Systems," Proceedings of the ASME Congress, Orlando, Florida, November 13-18, 2009, with K. M. Smith, D. E. Duvall and J. F. Grzetic

"Fracture Toughness Testing ($K_{IC}$) of PE 4710 Pipe Material," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Milwaukee, Wisconsin, May 4-7, 2008, with H. Svetlik and A. Shabeer

"Failure Investigation of XLPE Chemical Storage Tanks," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Milwaukee, Wisconsin, May 4-7, 2008, with D. E. Duvall

"Failure Analysis of a Large Diameter Heat-Fusible PVC Pipe in a Horizontal Directional Drilling Installation," Proceedings of the Society of Plastics Engineers

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"Failure Analysis of Polypropylene Used in a Hot Water Environment – Effects of Different Stabilizer Systems," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Cincinnati, Ohio, May 6-10, 2007, with L. J. Broutman and A. I. Kasner

"Phosphate Esters as Stress Crack Agents – Case Studies in Failure Analysis," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Cincinnati, Ohio, May 6-10, 2007, with A. I. Kasner

"Failure Prevention – Lessons from the Failure Analysis Investigations of Polymer Parts in Appliances," 57th Annual Conference of the International Appliance Technical Conference, Rosemont, Illinois, March 27-29, 2006, with A. I. Kasner and B. J. Gedeon

"Failure Analysis of a PEX Pipe Crimping System," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Boston, Massachusetts, May 1-5, 2005, with T. P. Jeka

"Steel Wire Reinforced Plastic Composite Pipe," Proceedings of the Society of Plastics Engineers Annual Technical Conference, Chicago, Illinois, May 16-20, 2004, with B. D. Agarwal and L. J. Broutman

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"An Alternative Method for Determining the Hydrostatic Design Basis for Plastic Pipe Materials," Proceedings of the International Plastic Pipe Symposium, Goteburg, Sweden, September 14-17, 1998, with L. J. Broutman, E. F. Palermo and A. R. Shah

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"Aging of Plastic Pipe Used for Natural Gas Distribution," Final Report to the Gas Research Institute, GRI Report No. 88/0285, December 1988, with L. J. Broutman, L. R. Nylander, et al.

"Analysis of Polyethylene Gas Pipe Field Failure at Clear Lake, Iowa," for National Transportation Safety Board, NTSB Accident No. DCA-83-AP-022, July 12, 1983, with L. J. Broutman

"Environmental Testing of High Strength Molding Compounds," Polymer Composites, 3(1), January 1982, with N. Sridharan; also presented at the Press Molders Committee Meeting of the Society of the Plastics Industry, Columbus, Ohio, 1981

# APPENDIX II

## Testimony List of Dale B. Edwards, P.E.

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**Dale B. Edwards, P.E.**

**LIST OF EXPERT DEPOSITION AND TRIAL TESTIMONY**

**Current billing rate: $340**

| Case Name | State | Deposition | Trial |
|---|---|---|---|
| **2011** | | | |
| JETEX, LLC, and Arch Insurance Company, v. Ross Scottsdale, LLC d/b/a Scottsdale Air Center<br>Case No. 2:09-CV-01561-NVW<br>United States District Court, District of Arizona | AZ | X | |
| Underground Solutions, Inc. v. P&F Distributors<br>Case No.: CIV-470876<br>Superior Court of California, San Mateo County | CA | X | |
| State Farm (Diehl) v. Fluidmaster, Inc.<br>Arbitration | AZ | | X |
| Rockingham Casualty Company, as Subrogee of Joseph A. George v. Fluidmaster, Inc.<br>Civil Action No. 10-1434/ United States District Court For The Western District of Pennsylvania | PA | X | |
| Bakelite Exposures in CVLO Federal MDL Asbestos Cases | | X | |

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| **2012** | | | |
| Metropolitan Insurance (Petit) v. Fluidmaster, Inc.<br>Arbitration | AZ | | X |
| State Farm General Insurance Company, v. Mercury Plastics, Inc., and Does 1-50, Inclusive<br>Case No. 30-2011 00493983<br>Superior Court of the State of California County of Orange, North Justice Center | CA | | X |
| Alan Furness and Caroline Furness v. Mercury Plastics, Inc.<br>Case No. 12-2-08218-9 SEA<br>Superior Court of Washington, King County | WA | X | |

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| **2013** | | | |
| FH, LLC, Washington Limited Liability Company v. Harvel Plastics, Inc.<br>Cause No. 11-2-02242-1<br>Superior Court of the State of Washington County of King, at Seattle | WA | X | |

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| State Farm Fire and Casualty Company, as Subrogee of Joseph Brandt v. Barbour Corporation, et al<br>Case No. CL11-13517<br>Circuit Court for the County of Fairfax, Virginia | VA | X | |
| James River Insurance Co. v. Triad Affiliates Inc., et al<br>Case No. 5:11-CV-00763<br>U. S. District Court, Western District of Louisiana | LA | X | |
| State Farm Fire & Casualty Co. a/s/o Andrew and Ellen Rosengard v. Fluidmaster, Inc.<br>Case No. CV12 0731<br>U.S. District Court for the Eastern District of New York | NY | X | |

| **2014** | | | |
|---|---|---|---|
| Allstate Property & Casualty a/s/o Zarzand Galstian v. Mercury Plastics<br>Case No. 2:13-cv-01763-RCJ-PAL<br>United States District Court, District of Nevada | NV | X | |

| **2015** | | | |
|---|---|---|---|
| Elliud Garcia Arguelles v. Fun Express, LLC, et al.<br>Case No. CL14-1281<br>Circuit Court, City of Hampton | VA | X | |

# Exhibit J

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# PROJECT REPORT

**REPORT NUMBER: SWA-112415-1-RP1**

**DATE: December 17, 2015**

**CLIENT INFORMATION:**
Swanson, Martin & Bell LLP
330 N. Wabash Ave., Suite 3300
Chicago, IL 60611
Attn: Christopher Sheean

**SAMPLE DISCRIPTION:**
The client provided the following documents:

1. Underground Solutions, Inc. v. Eugene Palermo, a/k/a Gene Palermo, Case No. 13-cv-8407 (i.e. the Amended Complaint).
2. “Characteristics of Butt Fusion Joints in Thermoplastic Pipe for Water Applications”, Dr. Gene Palermo, presented at: MRWA – March 7, 2012, IL AWWA – March 21 2012, and UIR International Conference and Trenchless Technology on June 5, 2012 (13 pages)
3. “Plastic Pipe for Water Distribution – What You Need to Know About RCP and Butt Fusion Integrity”, Dr. Gene Palermo, MRWA - 3/20/13, (63 slides/pages in PDF format, which presumably originated as a Powerpoint® presentation)
4. “Water Main Break Rates In the USA and Canada: A Comprehensive Study”, Dr. Steven Folkman, April 2012 (28 pages)
5. “Pipeline Rehabilitation with Expanded and Reoriented PVC”, D. Woods, T. Marti, and S. Ferry, 2003 (9 pages)
6. Eight (8) total reports promulgated by Underground Solutions, Inc. pertaining to butt fusion joint failures.

Additionally, various AWWA, ASTM, PPI and CFR documents were obtained independently and included:

7. AWWARF “Long-Term Performance Prediction for PE Pipes”, 2007
8. ASTM D1784-11
9. ASTM D1822-13
10. ASTM D2657-07
11. ASTM D3350-14
12. ASTM F2620-13
13. ASTM F2634-10
14. ASTM D2513-14e1
15. ASTM F1674-11
16. CFR Title 49, Subtitle B, Chapter I, Subchapter D, Part 192, Subpart F, Sections 192.283, 192.295, and 192.287.
17. PPI TR-33 2009 (and 2012) Generic Butt Fusion Joining Procedure for Field Joining of Polyethylene Pipe

**OBJECTIVE:** The client requested that PSILAB, Inc. read and provide opinions on the documents authored by Dr. Palermo, specifically Documents 2 and 3.

**BACKGROUND:**

Dr. Palermo's 2012 paper (Document 2) purports to offer a fair and balanced comparison of the performance of polyethylene (PE) and polyvinyl chloride (PVC) butt fusion joints. His 2013 PDF/Powerpoint presentation appears to contain significant amounts of the information contained within the 2012 paper, but in a more-brief format, although it also contains numerous images of fractured pipe that are offered as "evidence" supporting his paper and the need for additional testing and requirements for PVC butt fusion as a joining practice. However, upon delving into the details of these documents, and in conjunction with and comparison to other publicly available technical documents related to the subject of PVC butt fusions, it is clear that the work product authored by Dr. Palermo is incorrect on numerous points and thus quite misleading. The following information and opinions address this in a point by point manner. The opinions are offered based on the two documents in a linear page number progression, but overall three main points of contention are addressed:

1. The tests to characterize PE butt fusions are either completely inapplicable to PVC due to inherent material property differences, or at minimum would require different testing details and technical requirements for evaluation.
2. The procedures and methodologies proffered by Dr. Palermo as "industry standard" and/or "consensus standards" are not actually considered such, even for PE butt fusion joints.
3. The testing that Underground Solutions, Inc. has performed in order to determine PVC butt fusion strength and hence joint integrity appears to have been ignored completely by Dr. Palermo. The butt fusion joint strength research by Underground Solutions, Inc. has resulted in a very low empirical joint failure rate, which is better than any other piping system used to transport water.

**OPINIONS:**

A. Application of PE-specific test methods and material or product specification requirements to PVC materials and PVC butt fusion joints represents an egregious mistake, in that PE is a semi-crystalline material operating above its glass transition temperature (i.e. in the "rubbery" phase/state) while PVC is an amorphous material operating below its glass transition temperature (i.e. in the "glassy" phase/state).

B. First and foremost, there is no definitive process, set of testing methodologies, or procedure by which butt fusion piping joints are qualified for use in service. However, significant bodies of knowledge do exist in the marketplace where piping materials have been successfully joined by the butt fusion technique, and thus a historical path exists. Examples of this include butt fusion of PE and nylon pipe for use in natural gas distribution, butt fusion of PE pipe for use in water distribution, and butt fusion of PVDF piping which is typically used where chemical resistance is needed. Early in the product development cycle of Fusible® PVC, Underground Solutions, Inc., henceforth "UGSI", selected and performed testing that "mirrored" the testing that had been used to assure PE pipe butt fusion joints perform adequately when utilized in water distribution service, which is generally embodied within PPI TR-33 (Generic Butt Fusion Joining Procedure for Field Joining of Polyethylene Pipe). TR-33 was first issued in 1999 by PPI, revised in 2006, and then revised again in 2012. The earlier versions of TR-33 (circa 1999 and 2006) indicated the use of axial tensile strength testing and elevated temperature sustained pressure testing as indicators of joint strength (aka joint integrity). It should be noted here that the elevated temperature sustained pressure testing of PE samples with butt fusion joints provides some confidence in long-term performance, although at reduced stress in comparison to axial tensile testing of joints or coupons from joints which is a short-term strength measurement.

C. The early versions of the TR-33 document did not contain any reference to a tensile impact test method or requirement such as ASTM D1822 or F2634. Note that ASTM F2634 (the high speed tensile impact test method for PE butt fusion joints) actually did not exist at the time; ASTM F2634 was first published in 2007. ASTM F2634 appears for the first time in the 2012 version of TR-33, and ASTM D1822 has never been a part of this document to this day.

D. Due to inherent fundamental materials property differences between PE and PVC, elevated temperature sustained pressure testing is not a pertinent test method for PVC, so in their quest to understand long-term PVC butt fusion joint strength US performed testing at ambient temperatures for correspondingly longer test times.

E. UGSI has performed testing which far exceeds the current (as best that can be described as) "industry standard" for the long-term performance of a PVC butt fusion joint. The overall approach that UGSI took in determining if the PVC butt fusion joining technique was acceptable was that of determining if the joints could withstand the stress of pressurization in both short- and long-term testing, and that butt fused joints could withstand the stresses involved in installing pipe via a pulled-in-place technique. Testing that UGSI has performed to evaluate long term joint strength performance includes

   a. Extensive PVC butt fusion axial joint strength characterization and fusion operator qualification (i.e. consistent with PPI TR-33).
   b. Ambient temperature (23°C) sustained pressure testing in accordance with the product specification requirement (i.e. consistent with PPI TR-33).
   c. Hydrostatic Design Basis (HDB) testing (e.g. 6-inch nominal DR18 pipe tested to develop a PPI TR-3 E-2 data set; i.e. exceeding the requirements within PPI TR-33).
   d. Million plus cycle fatigue tests (e.g. 6-inch pipe through 3.5 MM cycles and 24-inch pipe through 1MM cycles; i.e. consistent with ASTM F1674).
   e. As such UGSI has embarked upon and completed a comprehensive testing program which closely mirrors that used in competing industries, as well as tests and requirements that exist for PVC.

F. If the two materials, PVC and PE, were from the same polymer family with similar materials properties and performance attributes, they would be expected to behave similarly when tested using the same method. However, since PE and PVC are markedly different materials, they essentially have two different sets of tests to characterize material and product performance. For PVC and PE the materials properties cell classification approaches and tests are different, the product quality control tests are different, and the product performance requirements are different. At its most simple level, material property, quality control, and product performance requirements exist to assure successful final product performance, and are thus typically targeted at critical performance parameters. In practice they are targeted at material and product minimum performance indicators, and/or weaknesses, and/or where historical experience has found problems. To take a "one size fits all" approach of comparative testing using "standard" test methods that are only applicable to PE is biased, with the results essentially preordained (to fail). Had the opposite approach been taken of performing comparative testing using PVC-specific testing methodologies the results would have been similarly biased with PVC of course performing better in comparison to PE. As a semi-absurd example, what Dr. Palermo has done with his documentation is the equivalent of determining that cars are "bad" because they do not meet the requirements for aircraft.

G. From a failure rate perspective, UGSI has a failure rate that is so low it is/would be the envy of any other material group or product line. While the exact number of failures is vigorously debated, it certainly does not exceed 50 total failures (butt fusion failures as well as ALL other failure modes). As reported by UGSI, over 10 million feet of pipe has been installed as of 2015, over an approximately 12 year span. This failure rate, when normalized to typical failure rate formats of # failures/100 miles of pipe/year, is less than that published for PE of 5.2 failures/100 miles/year and 2.6 failures/100 miles/year for classic bell and spigot PVC. Additionally, if failures due to workmanship and assembly issues are excluded, which is discussed within the studies cited, the calculated failure rate for Fusible PVC would be even lower. These published values are contained within Document 7, the AWWARF study titled "Long-Term Performance Prediction for PE Pipes", and Document 4, Dr. Steven Folkman's study titled "Water Main Break Rates In the USA and Canada: A Comprehensive Study", respectively.

Dr. Palermo's authored documents (e.g. 13 page paper and the 63 page PDF identified in Documents 2. and 3. Respectively, above) contain numerous examples of statements or opinions incorrectly presented as facts, observations, and conclusions. The following examples are offered, with rebutting statements and opinions offered by PSILAB:

H. Document 2: Page 1 Rebuttal: Within Section I, Abstract, of his 2012 paper titled "Characteristics of Butt Fusion Joints in Thermoplastic Pipe for Water Applications Dr. Palermo states "The purpose of this paper is to compare the characteristics of butt fusion joints for different thermoplastic pipes in standard tests performed similarly for each type of pipe." Of the "standard" tests chosen by Dr. Palermo, e.g. visual assessment per ASTM F2620, bent strap testing per D2657, tensile testing per D638, tensile impact testing per D1822, and high speed tensile impact per F2634, only ONE of these, D638, is applied to PVC piping materials within the ASTM and AWWA piping standards regimes. As for D638 specifically, the details of how the testing performed were completed using the PE-specific test parameters, while ignoring the PVC-specific test parameters. As such, while the overall comparative characterization looks to be technically valid, it is faulted at its most basic level due to wholesale inapplicability of the testing methods chosen. See the table below for details:

**Analysis of Dr. Palermo's proposed test methods for PVC butt fusion joints:**

| Test Method | Title | Notes | |
|---|---|---|---|
| **ASTM F2620** | Standard Practice for Heat Fusion Joining of **Polyethylene** Pipe and Fittings | Applicable to PE | **Not** Applicable to PVC |
| **ASTM D2657** | Standard Practice for Heat Fusion Joining of **Polyolefin** Pipe and Fittings | **Not** Applicable to PE | **Not** Applicable to PVC |
| **ASTM D638** | Standard Test Method for Tensile Properties of Plastics | Applicable to PE | Applicable to PVC |
| | ASTM D638 Testing Speed Required per PE or PVC Cell Classification | 2.0 ipm | 0.2 ipm |
| **ASTM D1822** | Standard Test Method for Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials | Applicable to PE | Applicable to PVC |
| | Contained within ANY pipe standard or pipe material specification (Yes/No) | **NO** | **NO** |
| **ASTM F2634** | Standard Test Method for Laboratory Testing of Polyethylene (PE) Butt Fusion Joints using Tensile-Impact Method | Applicable to PE | **Not** Applicable to PVC |

I. Document 2: Page 1 Rebuttal: Within Section I, Abstract, of his 2012 paper Dr. Palermo states "We subjected several butt fusion specimens to tensile testing and tensile impact testing to determine if the butt fusion joints exhibited significant ductile elongation and permanent necking, which is indicative of a properly made butt fusion joint." While the tensile impact test may have value for the